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HOPKINTON DAM
MERRIMACK RIVER BASIN, NH

DESIGN LETTER REPORT
HOPKINTON DAM

REMEDIAL MEASURES FOR
DOWNSTREAM OUTLET WALL

JULY 1997

US Army Corps
of Engineers
New England District

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13. ABSTRACT *(Maximum 200 words)*

The right side (east) outlet wall which separates the forebay pool from the stilling basin has been displaying consistent movement since construction of the dam. Measurements taken have shown that the movement is a combination of both frost action and lateral loading due to earth pressure. This report describes the types of measurements taken, the results and conclusions drawn from those measurements, and a discussion of alternatives for correcting the problem.

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1. Summary

The right side (east) outlet wall which separates the forebay pool from the stilling basin has been displaying consistent movement since construction of the dam. Measurements taken have shown that the movement is a combination of both frost action and lateral loading due to earth pressure. This report describes the types of measurements taken, the results and conclusions drawn from those measurements, and an analysis of alternatives for correcting the problem.

2. Description and History of Project

a. General

The Hopkinton Lake Project is part of one of the four reservoir projects that have been constructed in the Merrimack River Basin by the Corps of Engineers for flood control and other purposes.

Hopkinton Lake is located in the town of Hopkinton on the Contoocook River, approximately eighteen miles southwest from the confluence of the Contoocook and Merrimack Rivers at Penacook, New Hampshire (Plate 1). Construction of the project was started in November 1959 and completed in July 1963. An upstream permanent pool is kept at approximately El. 382 ft NGVD, stage 16 ft. The downstream forebay pool created by the Hoague-Sprague Dam, has an average spring and summer elevation near 380 ft NGVD and elevation 382 ft NGVD during the fall and winter. The Hopkinton Lake project was designed and built as part of the overall Hopkinton-Everett reservoir system.

b. Topography & Geology
(1) General

The Hopkinton Reservoir occupies low, flat, relatively wide areas in the pre-glacial Contoocook Valley which has been generally deeply filled with out wash deposits and till. The entire reservoir was occupied during the recessional phase of the last glaciation by connected pools or sluggish-current lakes impounded behind ice and debris barriers which caused temporary damming and diversion of the natural drainage. In the areas occupied by the transient pools, deposits of sand, silt and gravel occur. Till and till covered bedrock hills which rise above the lowlands form the perimeter of the reservoir. (Ref Periodic Inspection No. 1)

(2) Site Geology

The Contoocook River flows in a deep, narrow valley entrenched in glacial tills. The right abutment rises steeply from the river's edge, the left abutment is less steep and rises from a narrow flood plain which occupies the left side of the valley bottom. Bedrock is deeply buried at the site occurring throughout at depths of up to 90 feet. The overburden is generally till which is overlain on the abutments by a thin blanket of silt or fine sand and in the valley bottom by variable, thin deposits of recent alluvium, mostly sands and gravels. Occurring in and under the till are erratic deposits of laminated fine sand and clay, and stratified sands and gravels. The overburden at the dam site, both in the abutments and valley bottom consist mainly of till composed of gravelly, silty sand with cobbles and boulders. The till is characteristically variable, however clayey and gravelly phases are fairly common. All the till is very compact and relatively impervious. Within the limits of usual variability, the till in the abutments is generally homogeneous. In the valley bottom, however, where the till is overlain by superficial deposits of recent, river-washed silty sands and gravelly sands, numerous deposits of laminated silt and clay, stratified sands and laminated silt and clay intimately mixed with the till occur scattered within the main till mass. These deposits generally range from less than one foot to as much as eight feet in thickness but appear to have only limited horizontal continuity and are considered to be isolated lenses in the till.

c. Embankment and Appurtenant Structures Description

(1) Dam Embankment

The dam embankment is a rolled earth filled with rock fill slope protection. It is 790 feet long with a maximum height of 76 feet above stream bed. The top minimum elevation is 437.0 ft NGVD. The dam consists of a homogeneous section of impervious fill, with its slopes protected with a quarry-run type rock on gravel bedding. Embankment seepage is controlled by a vertical pervious fill gravel chimney drain located near the center of the embankment and connected to a horizontal downstream pervious blanket. The dam slopes are 1 on 2 and 1 on 2.5, with a 10-foot berm on the upstream slope at elevation 400, providing an access to the trash rack bars, and a downstream berm at elevation 384, providing an as access for maintenance to the stilling basin structure. A rock toe is provided downstream with gravel toe drains at both abutments. Foundation relief wells were provided at the downstream toe to control potential seepage and uplift development. The outlet works, located on a glacial till foundation on the left bank of the river, consists of an approach channel, gate tower, three conduits, stilling basins, an outlet channel, and a forebay pool.

(2) Stilling Basin.

The stilling basin for the two flood control conduits (No. 1 and No. 2) is partitioned by a concrete wall 85 feet long. Each conduit barrel discharges into a single U shaped concrete outlet,

whose invert at the conduit exit is EL. 365.5 ft NGVD. The invert of each outlet drops a height of 15.5 ft. in 50 ft. into the stilling basin to an elevation of 350.0 ft NGVD and at the same time merges into a single section (see plate 3). The end of the stilling basin is approximately 117 ft. from the exit of the conduits and at this point is a single U section whose inside width is approximately 66 feet with a sidewall on the right 35 feet above the floor of the stilling basin and on the left 22 feet above the floor. The stilling basin length is 65.0 feet The outside walls of the stilling basin are parallel to the centerline of the two floor control conduits. Two rows of concrete baffles and stepped end sill were provided. The elevation at top of the right side (east) concrete wall adjacent to the head water at Hoague-Sprague Dam, is 385.0 ft NGVD, 5 feet higher than the dam's flash boards. The top of the left side (west) wall of the stilling basin is elevation 377.0 ft NGVD.

(3) Effects of Hoague-Sprague Dam

The presence of the downstream Hoague-Sprague Corporation Dam, which has a normal operating pool elevation of 380.0 ft NGVD (winter pool el. 382 ft NGVD), introduces a hydrostatic loading condition in the design of the stilling basin. The right U-wall and T-wall adjacent to the pond have been designed as cantilevers off the base and loaded with the full hydrostatic pressure from the pond. Although drainage has been provided under the slab of the stilling basin, it has been neglected in the design due to the possibility of freezing or clogging of the weep holes with a resulting full hydrostatic head being applied to the underside of the base slab. The left wall has also been designed as a cantilever from the base but with hydrostatic pressure varying from full head at the base to zero at elevation 371 ft NGVD. Projections of the base slab were found to be necessary on each side of the stilling basin slab at the end section in order to maintain a balance of loads to keep the structure from floating under the full hydrostatic pressure.

(4) Outlet Portal for Forebay Conduit.

The forebay conduit (conduit No. 3) and outlet channel discharges into the downstream Hoague Sprague dam pool. The forebay outlet channel that is a 55-foot long U-shaped section. The wall which is adjacent to the stilling basin is extended 51 feet beyond the 55-foot long channel. The channel walls are reinforced concrete cantilever type walls with a common mat. The head wall is supported by the retaining walls on each side and the walls are butted against the head wall. The Hoague Sprague Dam located downstream of the dam is used to supply water to the nearby paper mill and hydropower unit. (See plate 4)

(5) Outlet Channel for Conduits No. 1 & 2

Below the stilling basin the outlet channel slopes up from elevation 353 ft NGVD, at a

rate of 3.0 feet in 100 feet to meet the existing river channel. The outlet channel bottom and side slopes are protected by quarry run type rock fill on gravel bedding.

(6) Spillway

The spillway is a concrete trapezoidal weir (ogee section) founded on bedrock and is located in Dike H-3. Weir crest elevation is El. 416 ft NGVD and the crest length is 300 feet.

d. Foundation Conditions at Outlet Works

The outlet structures were constructed along the left side of the valley bottom. As a result of the required elevation for the invert of the conduit, the conduits and the gate tower structures were founded on a zone of very compact gravelly silty sand (glacial till) at least 5 ft. thick. Below this zone are lenses, bands or strata of various soils interspersed in compact glacial till. It is indicated by available data that these interspersed zones are numerous in the foundation overburden for the conduit but that the soils in the zones are very compact. The foundation conditions for the gate tower were explored by three bore holes, FD-142, FD-145 and FD-155. At these locations, good continuous samples were obtained. Some zones of silt laminated with sandy silt and silty fine sand occur below the upper foundation zone of very compact till. The soils in these zones are compact and well consolidated. Data indicate that no significant sand zones exist in the upper 25 ft. of foundation overburden at the tower structure.

e. Right Side Outlet Wall Problem

The outlet retaining wall (T-wall and portions of the Stilling Basin U-wall) on the east side of the discharge channel is tilting outward into the outlet channel. Since 1967 movement of the wall has been realized. In May of 1973 two brass survey disks were installed on each monolith in order to monitor this movement. Tilt plates were installed in 1989 adjacent to the survey disk to further monitor the movements. Extensive movement has been recorded (see plates 15). The extent of this movement is discussed in the conclusion section of this report.

f. Forebay Dike Erosion

The downstream Forebay Pool is regulated by the Hoague-Sprague Dam. The pool is maintained at elevation 380 ft NGVD during the spring and summer months. In the fall flash boards are added in order to raise the pool two feet to elevation 382 ft NGVD. During the April 1987 event the rock slope protection in the forebay pool was eroded and deposited into the center of the discharge channel. The displaced rock was later placed back onto the slope using a back-hoe.

3. Reservoir Regulation Events

a. General Reservoir Regulation

Hopkinton Lake is one of five flood control projects that have been constructed in the Merrimack River basin by the Corps. Located on the Contoocook River in the town of Hopkinton, New Hampshire. It is operated to reduce flooding in downstream communities and to maintain recreational activities. The recreation pool at elevation 380 ft NGVD contains 700 acre feet of storage. This pool is maintained at a depth of about 14 feet and creates a 220-acre permanent pool. The flood control storage amounts to 70,100 acre feet with the pool filled to spillway crest. Since being placed in operation in 1963, the maximum impoundment at Hopkinton Lake occurred in April 1987, when the project was filled to elevation 415.8 ft NGVD (95 Percent full), or 0.2 feet below spillway crest elevation, 416.0 ft NGVD.

b. Maximum Impoundments

(1) 1987 Flood Event

The embankment was subjected to its highest impoundment to date with a maximum water surface elevation of 415.8 ft NGVD, stage 49.8 feet (0.2 feet below the spillway crest), 95% full. The embankment performed satisfactorily during this impoundment. The dam was inspected at the time of the flood by an Emergency Response Team from Geotechnical Engineering Division (GED). Several small clear seeps were observed emerging along the base of the downstream left abutment above El. 384 ft NGVD. These seepage flows were attributed to ground water draining off the left abutment and not seepage through the dam embankment. No abnormal seepage conditions such as piping, boils from through seepage, or sinkholes were observed by the team or reported by the Project Manager.

(2) June 1984 Flood

During June 1984, the embankment was subjected to its second highest impoundment to date with a maximum water surface of 407.5 ft NGVD, stage 41.5 feet (8.5 feet below spill- way crest). The dam was inspected at the time of the flood by an Emergency Response Team from GED. No abnormal seepage conditions such as piping, boils, or sinkholes were observed then by the team or subsequently reported by the Project Manager.

(3) March 1990 Pool

During March 1990, the embankment was subjected to its highest impoundment since piezometers three through 11 were installed in 1987 and 1988. The maximum water surface

during this small event was at El. 397.2 ft NGVD, stage 31.2 (18.8 feet below the spillway crest).

(4) August 1991 Pool

During the August 1991 event, the embankment was subjected to an impoundment of 394.6 ft NGVD, Stage 28.6 ft (21.4 feet below spill way crest). The dam was inspected at the time of the flood by an Emergency Response Team from GED. No abnormal seepage conditions such as piping, boils, or sinkholes were observed then by the team or subsequently reported by the Project Manager. During this time the forebay pool was empty (9 July to 24 October) for maintenance which caused the water elevations in the piezometers and relief wells on the left side of the outlet channel to drop.

4. Outlet Wall History and Monitoring

a. Original Wall Design

The right side (east) outlet retaining wall is a reinforced concrete cantilever type T-wall with a seepage and shear key at the heel (see plates 5 thru 11). The top of the east wall is at elevation 385.0 ft NGVD. The total length of the wall is 114.75 feet and it is divided into six monoliths with expansion joints. Monoliths No. 2 through No. 6 have tilted toward the outlet channel. Maximum tilt was observed at the top of the monoliths. The monoliths retain an impervious fill embankment designed to retain the forebay pool for the Hoague-Sprague Dam. The cantilever walls are analyzed based on the assumption that the wall stems will yield and they will experience active earth pressure. The wall thickness-height ratio shows that the walls are relatively less rigid compared to other structures. The 3' x 6' shear key at the heel will be mobilized and it will resist the passive pressure provided by the bearing pressure of the subgrade foundation materials. The passive resistance of the backfill developed at the toe is not considered because the constant water flow in the stilling basin may erode the backfill. Impervious material for the dam and dikes was obtained from required excavations in glacial till for Canal No. 1. The excavated till was very compact, gravelly, silty and clayey sand with only occasional boulders.

The loading conditions considered for the analysis of the outlet channel east wall are as follows: The structure satisfies all stability criteria for overturning, sliding and foundation bearing pressure, except for loading case R3 which is normal condition with seismic. During, the seismic condition the foundation bearing pressure at the toe exceeds the allowable bearing pressure of 8 ksf for monoliths No.2 and No.6. The resultant does not fall within the middle third of the foundation base. For monolith No.6 the factor of safety against sliding during an earthquake is less than 1.3. The loading conditions considered for the analysis of the outlet structure are as follows:

Case R1 Usual Loading: Backfill in place to final elevation. Surcharge (not applicable). Lateral and uplift pressures due to water (normal operating pool elevation 382.0 ft NGVD for Hoague-Sprague Dam and tail water elevation 365.5 ft NGVD in stilling basin).

Case R2 Extreme Loading: Flood condition is not applicable since structure is located at the end of the downstream side of the dam.

Case R3 Earthquake Loading: Load Case R1 with induced lateral load added (Refer to EM 111.225.2: Retaining Walls for description of Earthquake Loading).

b. Investigations of Movement

(1) General

Initial instrumentation for monitoring wall movement consisted of scribe marks at adjoining ends of monoliths No.11 and No.12. The set of scribe marks has shown a maximum relative movement of approximately 3-15/16 inches. In May of 1973, a survey was performed to establish a baseline along the top of the wall which has been used for measuring lateral movement of each monolith periodically. The tilt plates were installed in November 1989 to measure the cumulative rotation of the top of the wall (see plate 4). Tilt plate readings were taken simultaneously with periodic surveys when possible to facilitate a comparison between rotation and lateral movement. (See plates 16 thru 22)

(2) Surveys

The baseline which was established in the May 1973 survey runs along the top of the wall from the east concrete abutment of Hoague-Sprague Dam to the outlet works (see plate 4). The baseline comprises of 14 brass survey disks set horizontally on the top of the wall adjacent to the tilt plates. Surveys have been performed which have recorded the horizontal and vertical movement of each disk.

(3) Tilt Plates

(a) Data Collection

Seventeen tilt plates have been installed on the east and west stilling basin and outlet channel walls which are used to measure the movement of the wall. A Terra Tilt Meter, Model TT-2 is placed in the groves of the tilt plate in each of the four directions known as A+, A- (A axis), B+, and B- (B axis) and data is recorded for each direction. The A axis is perpendicular to the wall, and the B axis is parallel to the wall. The data read from the tilt meter is 2 sin θ, where θ is the angle of deflection. The readings are then entered on a Lotus 1-2-3 spreadsheet and the deflection angle θ is calculated. A negative deflection angle of the A axis indicates the wall is

rotating toward the stilling basin/outlet channel; a positive deflection angle of the A axis indicates the wall is rotating away from the stilling basin/outlet channel. Rotation of the B axis indicates the wall is rotating side to side.

Temperature data is also collected which is then converted into freezing and thawing degree days; a degree day being the average of the daily maximum and minimum temperatures minus 32 degrees F. Negative numbers represent freezing degree days and positive numbers represent thawing degree days.

(b) Interpretation and Evaluation

(i) Tilt Plates 1 & 15. (Plate 22)

Tilt Plates TP1 and TP15 are located on the east stilling basin U-wall. Plate 22 shows that the highest angle of deflection of TP1 occurred in March 1994 and for TP15 in January 1990 with rotations of -0.2636 and -0.2063 degrees respectively outward of the A axis, toward the stilling basin. The survey data shows the maximum horizontal movement at the top of the wall occurred in November 1994 and was close to 0.16 ft (1.92 in) for TP 1. Some of the horizontal movement and rotation noted occurred during December 1989/January 1990, the coldest month on record, with freezing degree days consistently near -17 (Max -31.5) for over a month. There is no survey data for TP 15. By May 1992 TP15 had rotated inward +0.0516 degrees; rotation then reversed back outwards towards the stilling basin to -0.0516 degrees. No rotation readings were taken during the 1990-91 and 1991-92 winters. TP1 had a maximum vertical movement in May 1994 of 0.068 ft (0.82 in) of heave.

(ii) Tilt Plates 2 & 3. (Plate 16)

TP2 and TP3 located on the east outlet retaining wall and both are on monolith No.6; TP2 is adjacent to the upstream construction joint and TP3 is adjacent to the downstream construction joint. Plate 16 shows TP2 and TP3 having maximum rotations of the A axis of -0.3037 and -0.3266 degrees respectively in January 1990. Rotation of the B axis was minimal as was the vertical movement. Horizontal movement at the top of the wall showed both moved 0.212 ft and 0.224 ft (2.5 inches and 2.9 inches). The maximum rotation and horizontal movement occurred during December 1989/January 1990. There was minimal rotation and movement, relative to December 1989, during the next two winters. Maximum vertical movements were 0.070 ft (0.84 in) and 0.066 ft (0.79 in) of heave respectively occurring in May 1994.

(iii)Tilt Plates 4 & 5. (Plate 17)

TP4 and TP5 are located on the east outlet retaining wall and both are on monolith No. 5; TP4 being on the upstream end and TP5 on the downstream end. Maximum rotation of the A

axis and maximum horizontal movement occurred in January 1990 (Plate 17). Maximum rotation of the A axis was -0.3266 degrees for both TP4 & 5 with corresponding horizontal movement of 0.216 and 0.203 ft (2.6 inches and 2.4 inches) outward toward the stilling basin. TP5's rotation of the A axis retreated back to -0.12 degrees by May 1990 and stayed there until April 1992, by March 1994 it moved outward to -0.3209 degrees. TP4's rotation of the A axis rotated back to near 0 degrees by April 1992 and then back to -0.1948 by March 1994. But TP4's rotation of the B axis gradually moved to near -0.0573 degrees while TP5's B axis rotation was near +0.0115. Maximum vertical movement was 0.067 ft (0.80 in) of heave for both TPs occurring in May 1994.

(iv)Tilt Plates 6 & 7. (Plate 18)

TP6 is located on the upstream end and TP7 is on the downstream end of monolith No. 4 of the east outlet retaining wall. Plate 18 shows maximum horizontal movement toward the outlet channel of TP6 and 7 was 0.21 ft and 0.197 ft (2.5 inches and 2.4 inches) respectively with -0.3266 degrees rotation of the A axis for both tilt plates in December 1989/January 1990. TP6 rotated back to near -0.1 degrees and TP7 rotated close to +0.0344 degrees by April 1992; by March 1994 TP6 reached -0.2521 degrees and TP7 was at -0.1776 degrees. As with TP4, TP7's B axis gradually rotated to -0.0745 degrees by April 1992 while TP6's B axis stayed near 0.0401 degrees. Maximum vertical movements were 0.040 ft (0.48 in) and 0.070 ft (0.84 in) of heave respectively.

(v) Tilt Plates 8 & 9. (Plate 19)

Data for TP8 and 9 is shown on Plate 19; TP8 is on the upstream side and TP9 is on the downstream side of monolith No. 3 on the east outlet retaining wall. Maximum horizontal movement and rotation of the A axis occurred during December 1989/January 1990 when the degree days were consistently freezing for over a month. Rotation of the A axis was maximum in January 1990 with -0.2979 and -0.2922 degrees for TP 8 & 9 . Maximum horizontal movement was 0.183 ft (2.2 in) for TP8 and 0.201 ft (2.4 in) for TP9 in January 1990. Maximum vertical movement was 0.067 ft (0.80 in) of heave for both TP's occurring in May 1994.

(vi)Tilt Plates 10 & 11. (Plate 20)

Plate 20 shows the data for TP10, upstream, and TP11, downstream, both on monolith No. 2 on the east outlet retaining wall. Maximum horizontal movement was 0.221 ft in January 1990 and 0.200 ft in March 1996, for TP10 and 11 respectively, outward. Maximum rotation of the A axis for TP10 was -0.2349 degrees and for TP11 -0.2120 degrees. TP10's B axis gradually rotated to -0.0745 degrees, while TP11's B axis gradually rotated to 0.0630 degrees, both by

March 1996. Maximum vertical movements were 0.068 ft (0.82 in) and 0.060 ft (0.72 in) of heave respectively occurring in May 1994.

(vii)Tilt Plates 12 & 13. (Plate 21)

Data for tilt plates 12 and 13 are shown on Plate 21. TP12 and 13 did not respond as significantly to the December 1989/January 1990 winter temperatures as with the other tilt plates. Maximum horizontal movement of TP 12 occurred in January 1990 and was 0.063 ft (0.75 in) while TP13's maximum horizontal movement was 0.035 ft (0.42 in) both occurring in December 1989 and both moving horizontally toward the outlet channel. In December 1989/January 1990, both tilt plates' A axis rotated -0.0802 degrees. By April 1992, TP12's A axis had rotated to +0.0859 degrees inward; TP13 had also rotated toward the forebay pool to +0.0573 degrees. Both plates' B axis rotated to near +0.05 degrees in October 1990; TP12 then rotated back toward -0.0172 degrees and TP13 to near -0.0516 degrees by March 1996. Maximum vertical movements were 0.055 ft (0.66 in) and 0.052 ft (0.62 in) of heave respectively both occurring in May 1994.

(viii)Tilt Plates 14, 16 & 17.

TP14 is located on the east abutment of the Hoague-Sprague Dam adjacent to TP13, TP16 is located on the west stilling basin wall, and 17 is located on the west outlet retaining wall. Maximum horizontal movement of TP14 is 0.035 ft (0.42 in) which occurred in December 1989/January 1990; vertical movement over time has been minimal. Survey data for TP's 16 and 17 is not available. Maximum rotation of the A axis for TP14 is -0.0344 degrees outward and of the B axis is -0.0516 degrees; both occurring in October 1990. Maximum rotation of the A axis of TP16 and 17 was +0.0516 and +0.0458 away from the spillway respectively occurring in March 1995. Maximum rotation of the B axis was +0.0344 degrees in March 1995 for TP16 and +0.0401 degrees in August 1990 for TP17. These three tilt plates were not affected as adversely as TP 1-15 in December 1989/January 1990 possible because the backfill materials are very pervious and non frost susceptible.

5. Conclusions

a. Extent of Movement

Relative to their position on 15 May 1973, all of the monoliths, except for the first (No.1) upstream of the Hoague-Sprague dam abutment, have moved horizontally an average of almost 2-1/2 inches outward toward the stilling basin and outlet channel (see plate 15). During the fifth Periodic Inspection it was observed that monolith No. 2, upstream of the Hoague-Sprague dam abutment had tilted outward relative to monolith No. 1 by 3-15/16 inches at the top of the wall.

Relative movements from zero to 9/32 inch were also noted between other monoliths along the wall during Periodic Inspection No. 4. These monoliths have been steadily moving at a rate of about ½-inch every five years since monitoring was initiated in 1967.

b. Influence of Forebay Pool

It has been determined that the change in pool elevation between summer (elev. 380 ft NGVD) and winter (elev. 382 ft NGVD) has little effect on the outlet wall. The two foot change in pool elevation represents a negligible force acting on the wall.

c. Frost Effects

In December 1994 personnel from the Cold Region Research and Engineering Laboratory (CRREL) installed various instrumentation to monitor frost effects. The installed instrumentation includes 31 thermistor-type temperature sensors, one load cell, a vibrating wire inclinometer assembly and two linear motion potentiometers. As of 14 August 1996, maximum pressures in the load cell had reached 26 psi and total deflections of more than 3/4 inches have been measured along the wall. CRREL's inclinometer data suggest that the movement in the wall may be a combination of rotation about a point and deflection of the wall. The thermocouple data indicates that the limits of soil freezing behind the wall are as follows (see appendix C):

-at the top of the clay layer (approx. elev. 383 ft NGVD) frost reaches at least 6' east of the inside of the wall.
-at 8' down from the top of the wall (approx. elev. 377 ft NGVD) frost reaches between 2' and 4' east of the wall.
-at 12' down from the top of the wall (approx. elev. 373 ft NGVD) frost reaches 1 foot east of the wall.

d. Structural Analysis

A complete structural analysis of the outlet wall was performed by the design division. The analysis takes into account that the wall is cracked and assumes uniform frost loading. It is not anticipated that any repairs will be required on the wall. Measured deflections caused by soil and frost loading generally compare to the expected theoretical deflections. See Appendix A for the structural report.

6. Discussion of Alternatives

a. General

The alternatives considered for this project were, the replacement of the special impervious material with a pervious fill and drainage, install a thermal membrane for insulation against freezing, and the do nothing alternative. It has been determined from monitoring that the do nothing alternate would be unacceptable. If movement continues at the current rate, the stem of the outlet wall can produce severe cracks and break. Current movement in the wall would require an alterative that would relieve frost pressures behind the outlet wall, prevent frost from reaching the existing soils behind the wall or both.

b. Repair Alternatives

(1) Thermal Membrane

This alternative considers the installation of a thermal membrane between the outlet wall and the existing special impervious soils. This membrane would, for the most part, prevent frost which crosses the wall from reaching the soil behind it. However, for extended periods of freezing weather, it is not reasonable to expect no frost to penetrate the membrane into the impervious soil region. In addition, water is always present behind the wall stem and ice lenses may still develop behind the wall. For this reason a thermal membrane by itself would not be sufficient protection against frost.

(2) Replacement of Impervious Fill

This alternative would require removal of the special impervious fill behind the outlet wall and placement of a pervious non-frost susceptible fill with a drainage system. This design would prevent frost loads from building up by allowing the water to drain freely. This would prevent the formation of ice lenses in the zone immediately behind the wall. However, if frost was to consume the entire pervious zone and reach the back side of the embankment section, frost loading could reoccur on the wall. The wall may also have frost loading problems if the drainage system were to freeze. However, based on the thermocouple data and further studies done by CRREL it is not likely that either one of these would occur.

7. Recommendations

The recommended action is the replacement of the impervious fill with a 4 foot wide pervious zone and drainage system (see plates 7 thru 14). Based on studies done by CRREL, this design would provide protection for up to a one hundred year event. Construction of this option would require coordination with the Hoague-Sprague Dam, as the forebay pool would have to be drained. Furthermore the design would require specific material specifications.

a. Soil Materials

In general, excavated materials will be reused if they meet the required specification. A description of the necessary materials follows.

(1) Impervious Fill Material

Materials excavated from the existing impervious fill area will be reused in the areas designated for impervious fill material. Impervious fill will consist of a well-graded, natural, unprocessed soil containing sand, and silt or clay sizes. Impervious fill materials should be reasonably well-graded within the following limits.

Sieve Size (U.S. Standard)	Percent Passing by Dry Weight
6-inch	100
3-inch	85-100
No. 4	60-95
No. 40	35-75
No. 200	20-50

(2) Pervious Fill Material

Pervious fill material will be furnished by the contractor in accordance with Section 520, Fine Aggregate, of the State of New Hampshire Department of Transportation's, Standard Specifications for Road and Bridge Construction. Pervious fill material should be a uniformly graded washed sand and conform to the following gradation:

Sieve Size (US Standard)	Percent Passing by Dry Weight
3/8"	100
No. 4	95-100
No. 16	45-80
No. 50	10-30
No. 100	2-10
No. 200	0-3

(3) Stone Protection Materials

The Contractor can reuse existing suitable stone protection materials. Stone protection material should be well graded between the maximum and minimum stone sizes. The maximum and minimum sizes should produce a material without "skip gradation" with stone sizes within the limits specified. The rock will be placed so that the entire finished surface of stone protection will be of uniform appearance.

(4) Gravel Bedding

Gravel bedding materials will be furnished by the contractor and will consist of sand, gravel or crushed stone composed of tough, durable particles. Gravel bedding will be in accordance with Section 304, Item No. 304.2, of the State of New Hampshire Department of Transportation's, Standard Specifications for Road and Bridge Construction. The materials should be graded within the limits specified below:

Sieve Size (U.S. Standard)	Percent Passing by Dry Weight
6-inch	100
No. 4	25-70
No. 200	0-12

(5) 3/4"Crushed Stone Bedding for Drains

Bedding shall be furnished by the contractor and in accordance with Section 703, Standard Stone Size #67, of the State of New Hampshire Department of Transportation's, Standard Specifications for Road and Bridge Construction. Bedding should conform to the following gradation:

Sieve Size (U.S. Standard)	Percent Passing by Dry Weight
1"	100
3/4"	90-100
3/8"	20-55
No. 4	0-10
No. 8	0-5

(6) Crushed Stone Material on Top of Dike

Crushed stone will be contractor furnished material composed of hard, durable, and sound particles. Crushed stone will be in accordance with Section 304, Item No. 304.5, of the State of New Hampshire Department of Transportation's, Standard Specifications for Road and Bridge Construction. The material should be well-graded within the following limits:

Sieve Size (U.S. Standard)	Percent Passing by Dry Weight
3-1/2-inch	100
3 inch	85-100
1-1/2-inch	60-90
3/4 inch	40-70
No. 4	15-40
No. 200	0-5

b. Pipe Material

8" Corrugated Polyethylene (PE) pipe will be used for the drainage system (see plate 14). Circumferential slots shall be cleanly cut so as not to restrict the inflow of water and uniformly spaced along the length and circumference of the tubing. Width of slots shall not exceed 1/8 inch or be less than 1/32 inch. Rows of slots shall be symmetrically spaced so that they are fully contained in quadrants of the pipe.

8. References

Reference is made to the following documents pertinent to the basic design and construction of the dam and its operational history:

a. Design Memorandum No. V, Hopkinton- Everett Reservoir, Geology and Soils, Part B: Hopkinton Reservoir, February 1959.

b. Design Memorandum No. VIII, Hopkinton- Everett Reservoir, Detailed Design for Spillway Weir, Outlet Works, and Miscellaneous Structures, February 1959.

c. Periodic Inspection Report No. 4, Hopkinton Lake, April 1992.

d. Master Water Control Manual, Merrimack River Basin, August 1977.

e. Periodic Inspection Report No. 1, Hopkinton Lake, March 1973.

f. Review of Structural Stability, Hopkinton Lake Dam. Hydraulic & Water Resources Engineers, Inc., October 1989.

g. State of New Hampshire - Department of Transportation, Standard Specification for Road and Bridge Construction, 1990

HOPKINTON-EVERETT LAKES
NEW HAMPSHIRE

VICINITY MAP

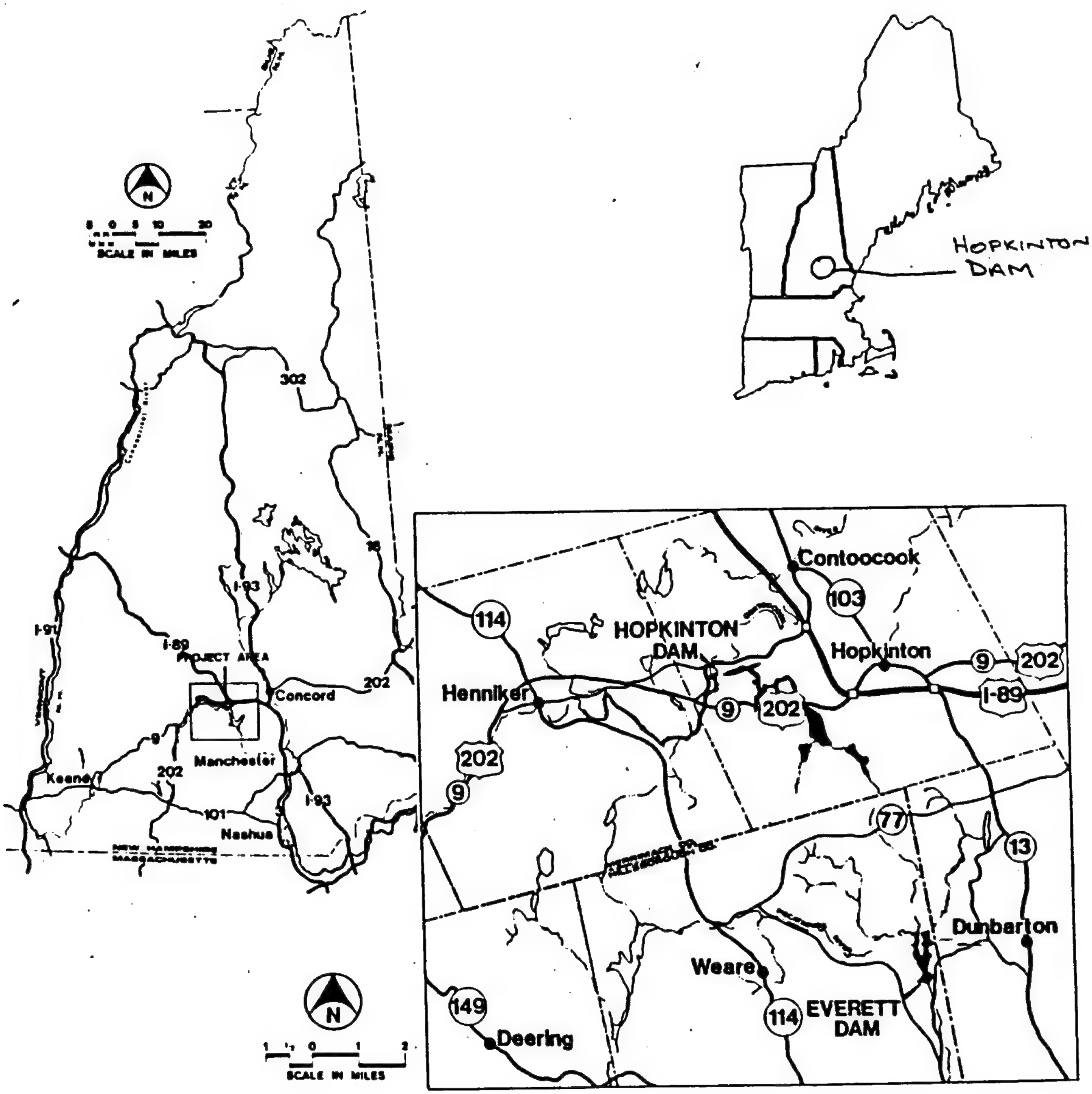


PLATE 1

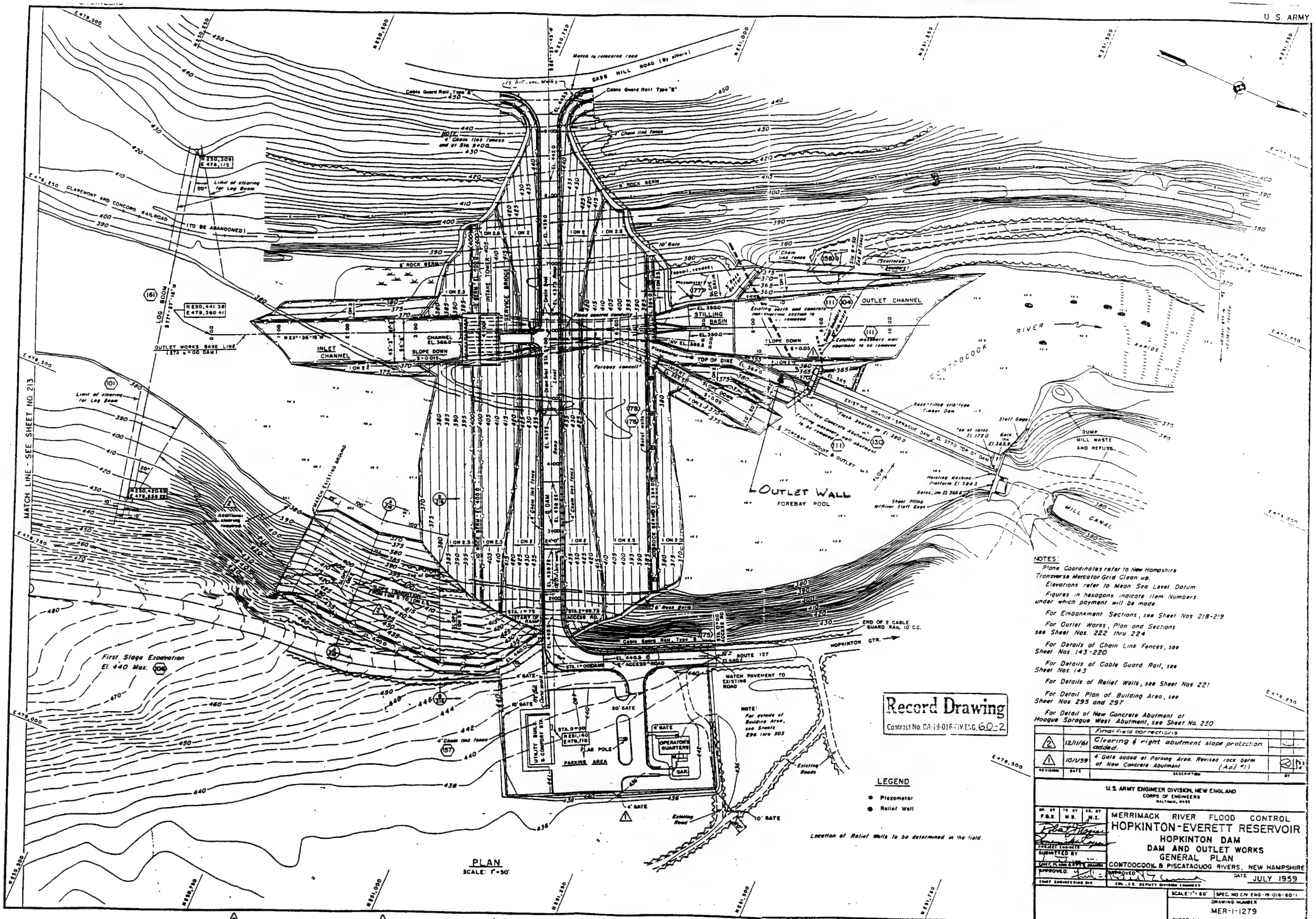
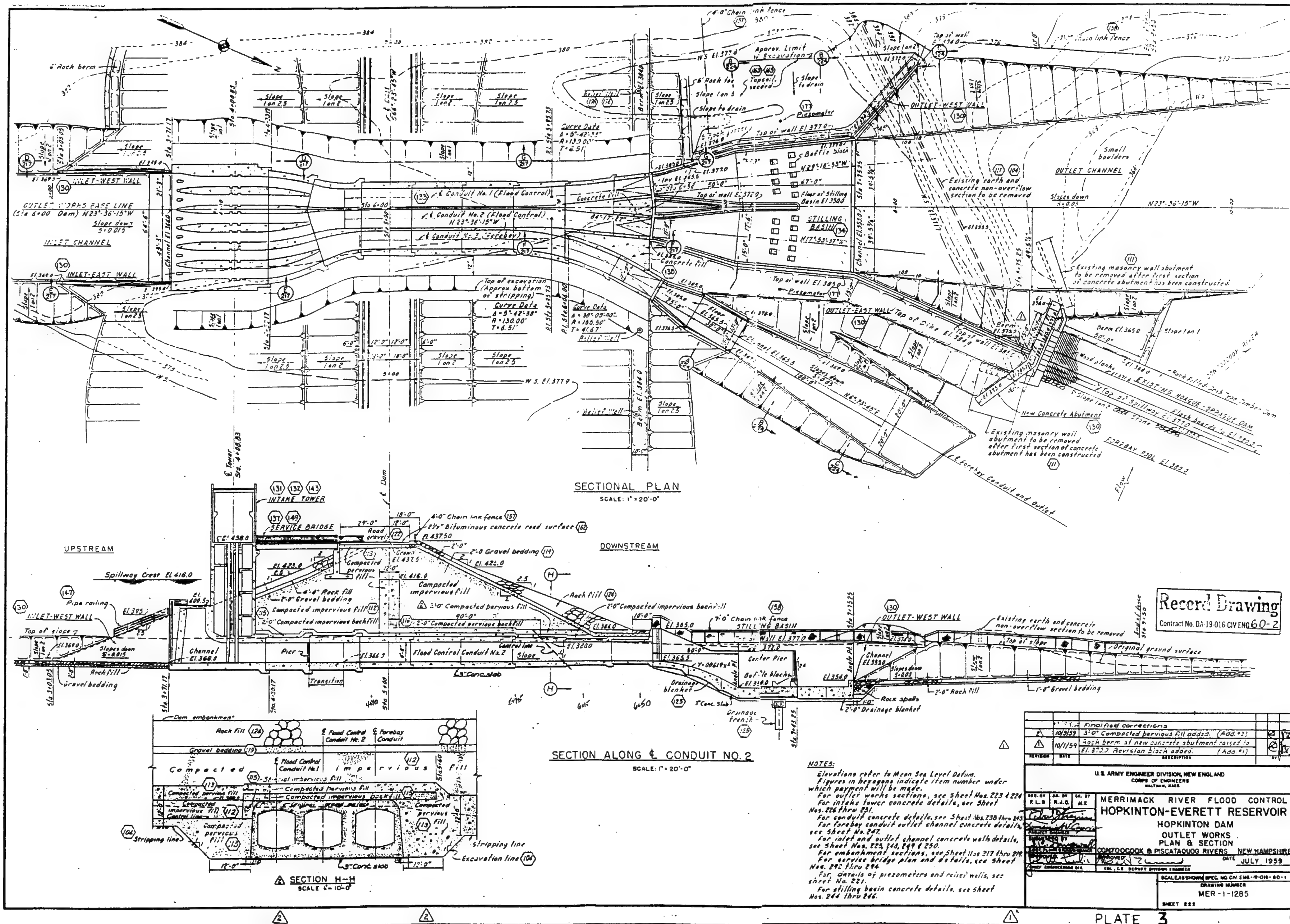
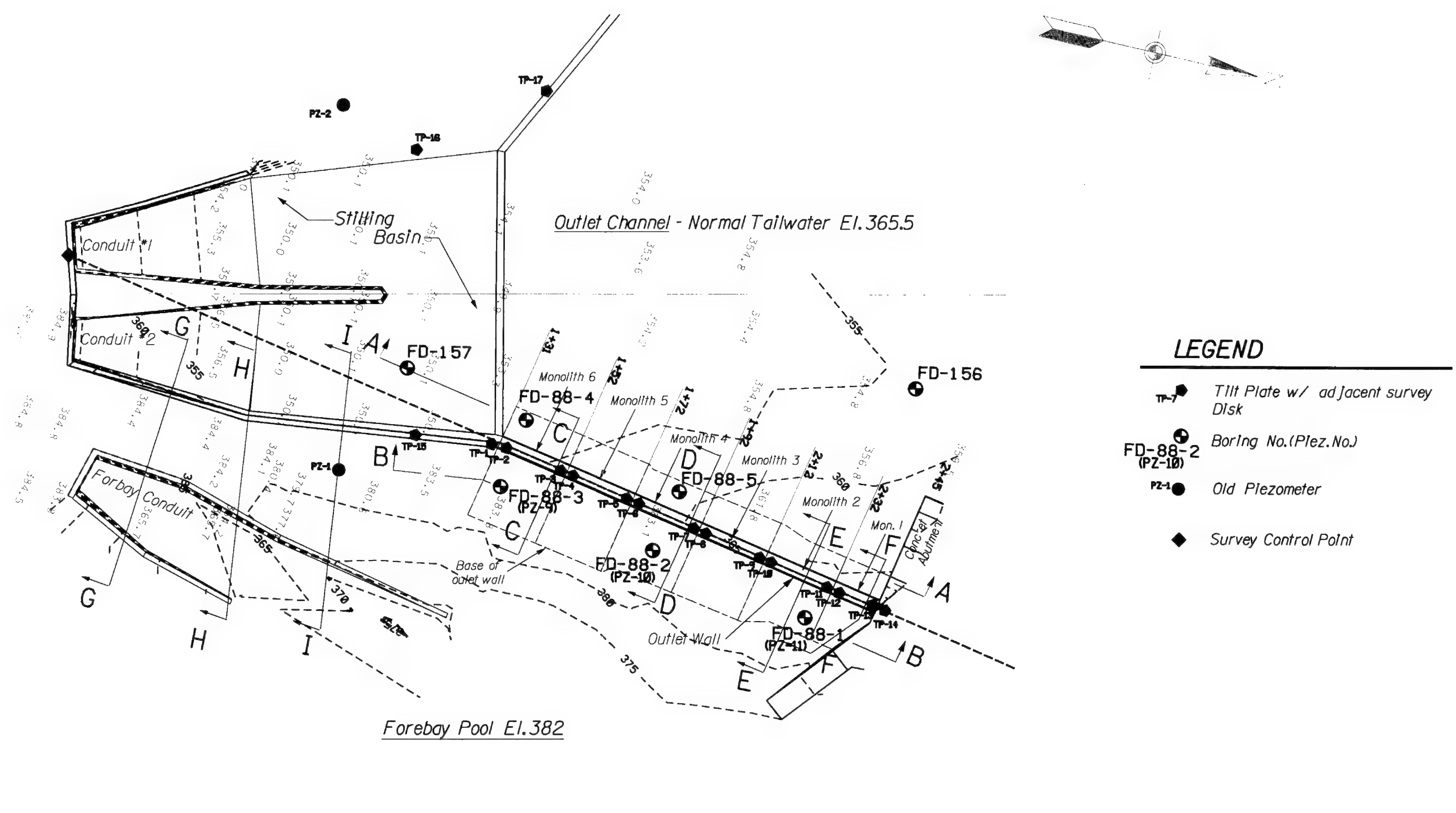

U S ARMY
CASS HILL ROAD (By others)
Match to relocated road
Cable Guard Rail Type "B"
CLAREMONT AND CONCORD RAILROAD (TO BE ABANDONED)
LOG BOOM
OUTLET WORKS BASE LINE
INLET CHANNEL
SLOPE DOWN
SERVICE BRIDGE
INTAKE TOWER
STILLING BASIN
OUTLET CHANNEL
TOP OF DIKE
RIVER
CONTOOCOOK
DUMP
MILL WASTE AND REFUSE
MILL CANAL
OUTLET WALL
FOREBAY POOL
First Stage Excavation El. 440 Max.
ROUTE 127
HOPKINTON CTR.
ACCESS ROAD
PARKING AREA
FLAG POLE
OPERATOR'S QUARTERS
UTILITY BLDG. & COMFORT STA.
Location of Relief Wells to be determined in the field.
MATCH LINE - SEE SHEET NO. 213
PLAN
SCALE: 1"=50'
LEGEND
Piezometer
Relief Well
Record Drawing
Contract No. DA-19-016-CIV ENG-60-2
NOTES:
Plane Coordinates refer to New Hampshire Transverse Mercator Grid Clean up.
Elevations refer to Mean Sea Level Datum
Figures in hexagons indicate Item Numbers under which payment will be made.
For Embankment Sections, see Sheet Nos 218-219
For Outlet Works, Plan and Sections see Sheet Nos. 222 thru 224
For Details of Chain Link Fences, see Sheet Nos. 143-220
For Details of Cable Guard Rail, see Sheet Nos. 143
For Details of Relief Wells, see Sheet Nos 221
For Detail Plan of Building Area, see Sheet Nos 295 and 297
For Detail of New Concrete Abutment at Hoague Sprague West Abutment, see Sheet No. 250
Final field corrections
2 12/11/61 Clearing & right abutment slope protection added.
1 10/1/59 4' Gate added at Parking Area. Revised rock berm at New Concrete Abutment (Add #1)
REVISION DATE DESCRIPTION BY
U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS
MERRIMACK RIVER FLOOD CONTROL
HOPKINTON-EVERETT RESERVOIR
HOPKINTON DAM
DAM AND OUTLET WORKS
GENERAL PLAN
CONTOOCOOK & PISCATAQUOG RIVERS, NEW HAMPSHIRE
DATE JULY 1959
SCALE: 1"=50'
SPEC. NO CIV ENG-19-016-60-1
DRAWING NUMBER
MER-1-1279
SHEET 216

PLATE 2

(216)


SECTIONAL PLAN
SCALE: 1" = 20'-0"
INLET-WEST WALL
INLET-EAST WALL
INLET CHANNEL
OUTLET WORKS BASE LINE
(Sta 6+00 Dam) N23°-36'-15"W
OUTLET-WEST WALL
OUTLET-EAST WALL
OUTLET CHANNEL
STILLING BASIN
℄ Conduit No. 1 (Flood Control)
℄ Conduit No. 2 (Flood Control) N23°-36'-15"W
℄ Conduit No. 3 (Forebay)
Existing earth and concrete non-overflow section to be removed
Existing masonry wall abutment to be removed after first section of concrete abutment has been constructed
New Concrete Abutment
EXISTING HOAGUE-SPRAGUE DAM
FOREBAY POOL El. 380.0
℄ Forebay Conduit and Outlet
SECTION ALONG ℄ CONDUIT NO. 2
SCALE: 1" = 20'-0"
UPSTREAM
DOWNSTREAM
INTAKE TOWER
SERVICE BRIDGE
Spillway Crest El. 416.0
SECTION H-H
SCALE 1" = 10'-0"
Record Drawing
Contract No. DA-19-016-CIVENG-60-2
NOTES:
Elevations refer to Mean Sea Level Datum.
Figures in hexagons indicate item number under which payment will be made.
For outlet works sections, see Sheet Nos. 223 & 224.
For intake tower concrete details, see Sheet Nos. 226 thru 231.
For conduit concrete details, see Sheet Nos. 238 thru 243.
For forebay conduit outlet channel concrete details, see Sheet No. 247.
For inlet and outlet channel concrete walls details, see Sheet Nos. 225, 248, 249 & 250.
For embankment sections, see Sheet Nos 217 thru 219.
For service bridge plan and details, see Sheet Nos. 292 thru 294.
For details of piezometers and relief wells, see sheet No. 221.
For stilling basin concrete details, see sheet Nos. 244 thru 246.
Final field corrections
2 | 10/3/59 | 3'-0" Compacted pervious fill added. (Add. #2)
1 | 10/1/59 | Rock berm at new concrete abutment raised to El. 372.0. Revision block added. (Add. #1)
U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS
WALTHAM, MASS.
MERRIMACK RIVER FLOOD CONTROL
HOPKINTON-EVERETT RESERVOIR
HOPKINTON DAM
OUTLET WORKS
PLAN & SECTION
CONTOOCOOK & PISCATAQUOG RIVERS NEW HAMPSHIRE
DATE JULY 1959
SCALE AS SHOWN
SPEC. NO. CIV. ENG.-19-016-60-1
DRAWING NUMBER
MER-1-1285
SHEET 222
PLATE 3
222



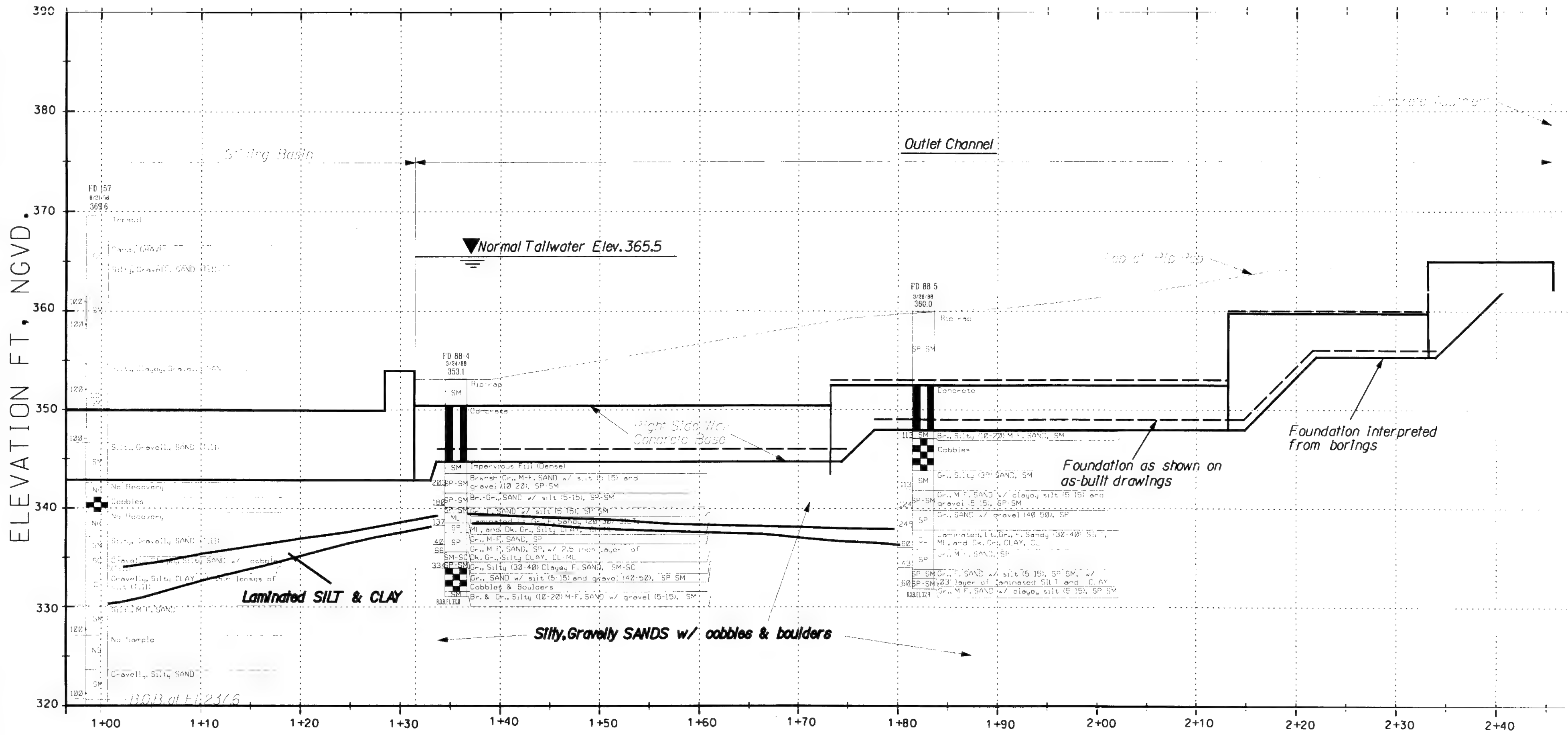
GRAPHIC SCALES

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

EXPLORATION & INSTRUMENTATION
PLAN

4

APRIL 1997



ENGINEERING LOG PROFILE A-A ALONG RIGHT SIDE (EAST) OUTLET WALL

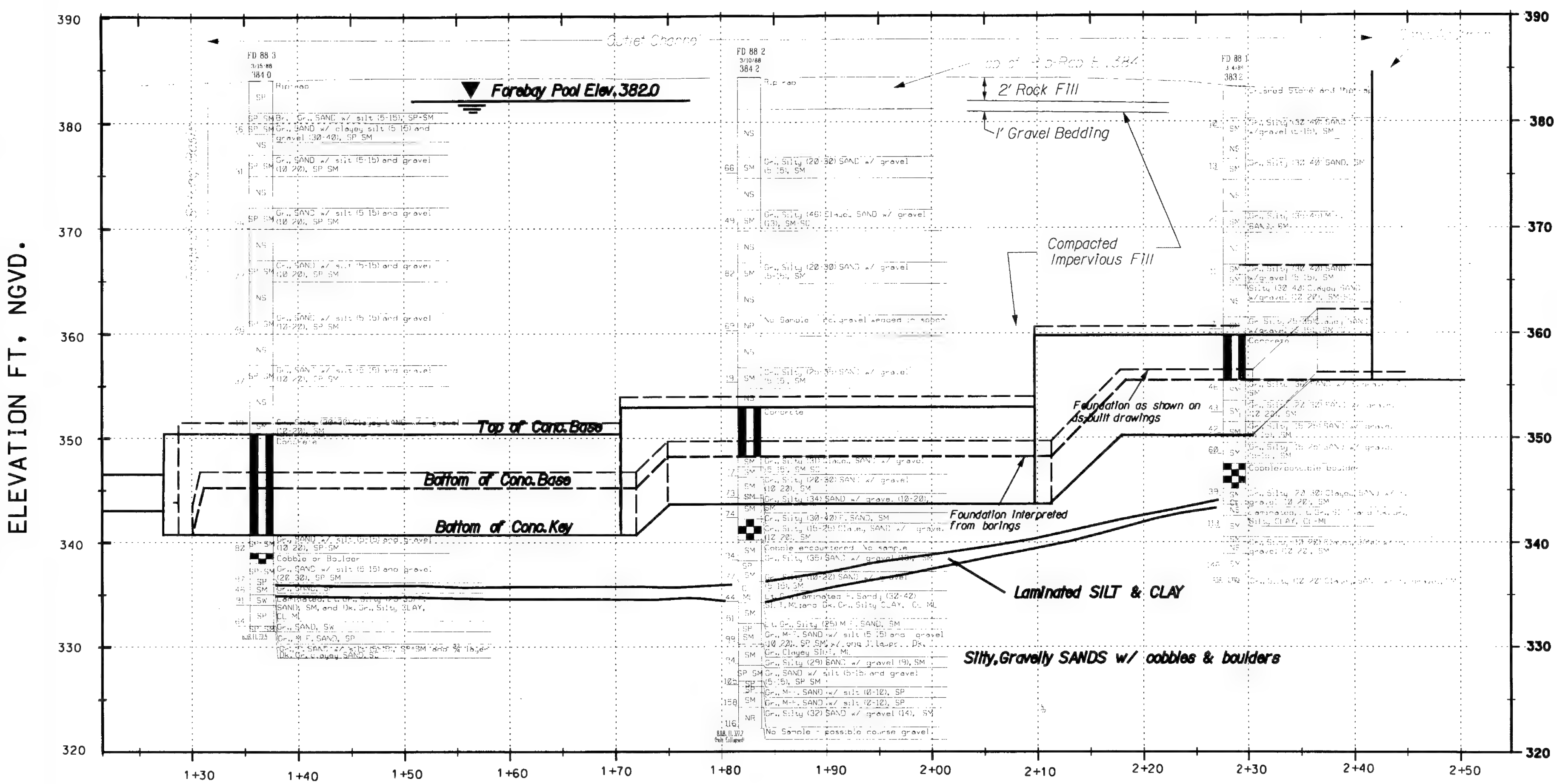
LEGEND FOR GRAPHIC LOG

FD87-6	Type, year, and number of exploration
EL. 494.7	Elev. of ground surface.
SM	Group letter symbol according to ASTM D2487and ASTM D2488
NR	No recovery or unsatisfactory soil sample recovered
NS	Not sampled
	Subsurface water level in boring during time of exploration
25	Number of blows per foot of penetration using a 140lbs. hammer falling freely an average drop of 30" to drive a sample spoon of 2" O.D. – 1-3/8" I.D. in size
▪	Blow count not recorded or not considered representative

	Cobbles or boulders or Concrete (Core-drilled)
	Cobbles or boulders, continous or nested.
El. 488.6	Elevation of bedrock surface
	Rock core recovery 0 – 25 %
	Rock core recovery 25 – 50 %
	Rock core recovery 50 – 75 %
	Rock core recovery 75 – 90 %
	Rock core recovery 90 – 100 %
El. 488.6	Elevation at bottom of exploration

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

Hopkinton Outlet Wall
Engineering Log Profile A-A



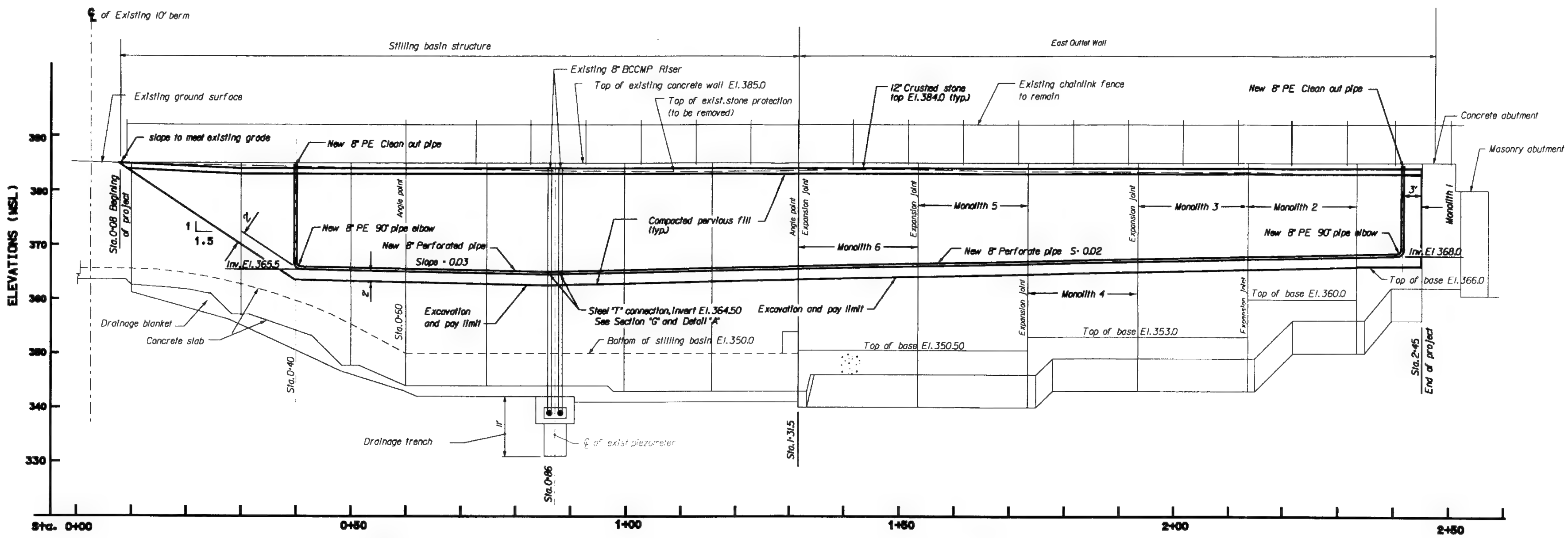
ENGINEERING LOG PROFILE B-B ALONG RIGHT SIDE (EAST) OUTLET WALL

LEGEND FOR GRAPHIC LOG

- FD87-6 — Type, year, and number of exploration
- EL. 494.7 — Elev. of ground surface.
- SM — Group letter symbol according to ASTM D2487and ASTM D2488
- NR — No recovery or unsatisfactory soil sample recovered
- NS — Not sampled
- ◀ — Subsurface water level in boring during time of exploration
- 25 — Number of blows per foot of penetration using a 140lbs. hammer falling freely an average drop of 30" to drive a sample spoon of 2" O.D. - 1-3/8" I.D. in size
- * — Blow count not recorded or not considered representative

- Cobbles, boulders or concrete (Core-drilled)
- Cobbles or boulders, continous or nested.
- El. 488.6 Elevation of bedrock surface
- Rock core recovery 0 - 25 %
- Rock core recovery 25 - 50 %
- Rock core recovery 50 - 75 %
- Rock core recovery 75 - 90 %
- Rock core recovery 90 - 100 %
- El. 488.6 Elevation at bottom of exploration

Hopkinton Outlet Wall
Engineering Log Profile B-B



PROFILE OF PROPOSED REMEDIAL WORK - ALONG INSIDE FACE OF RIGHT SIDE (EAST) CONCRETE WALL

SCALE: 1" = 10'

GRAPHIC SCALES:

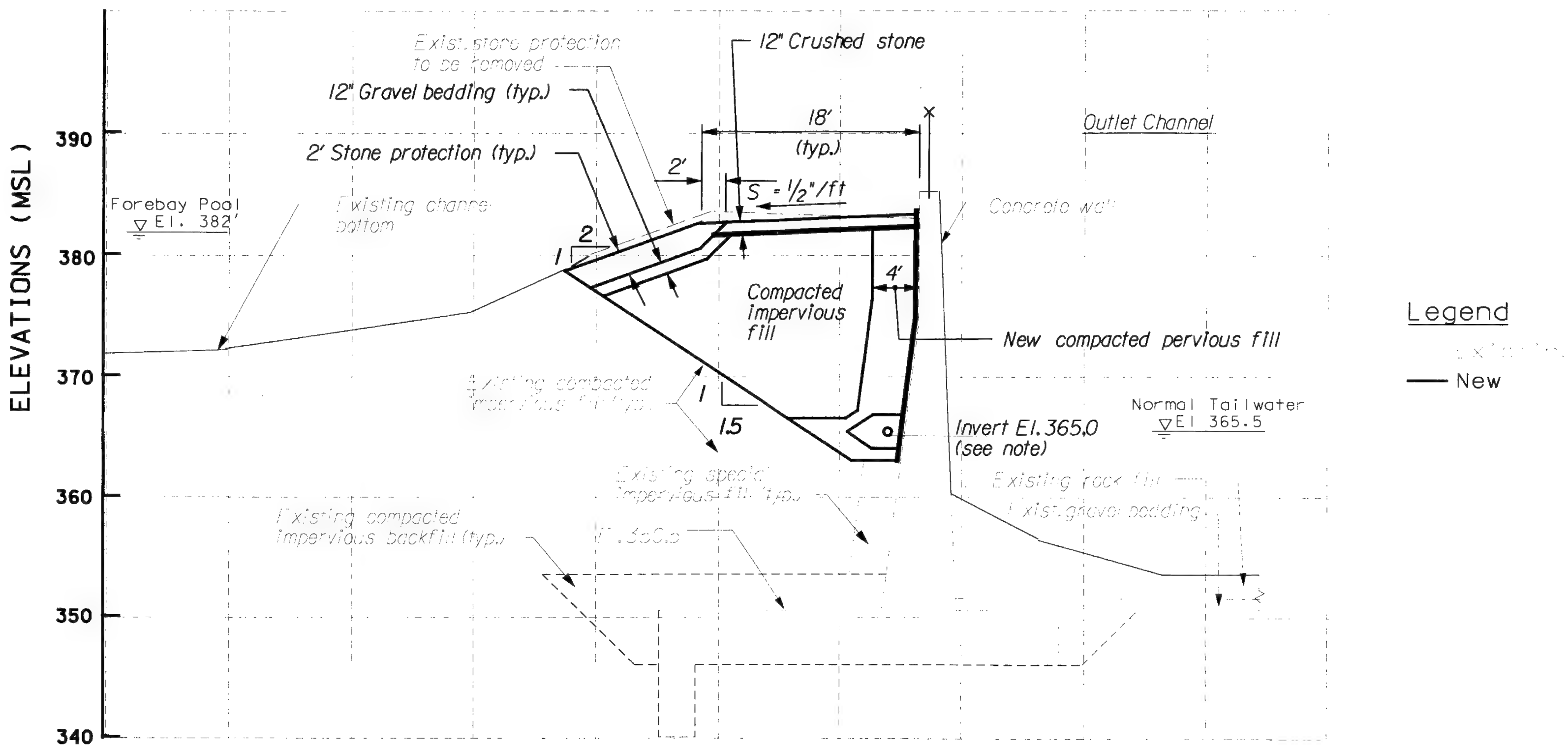
1" = 10' 10 5 0 10 20FT

Legend

—— New Work

—— Existing

DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASSACHUSETTS	
RP DESIGN BY MAV CHECK BY RP DRAWN BY	MERRIMACK VALLY FLOOD CONTROL HOPKINTON DAM HOPKINTON OUTLET WALL Profile Right Side(East) Outlet Wall CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 7	SCALE: AS SHOWN DATE: APRIL 1997



PROPOSED REMEDIAL WORK - SECTION C
STATION 1+50

SCALE: 1"=10'

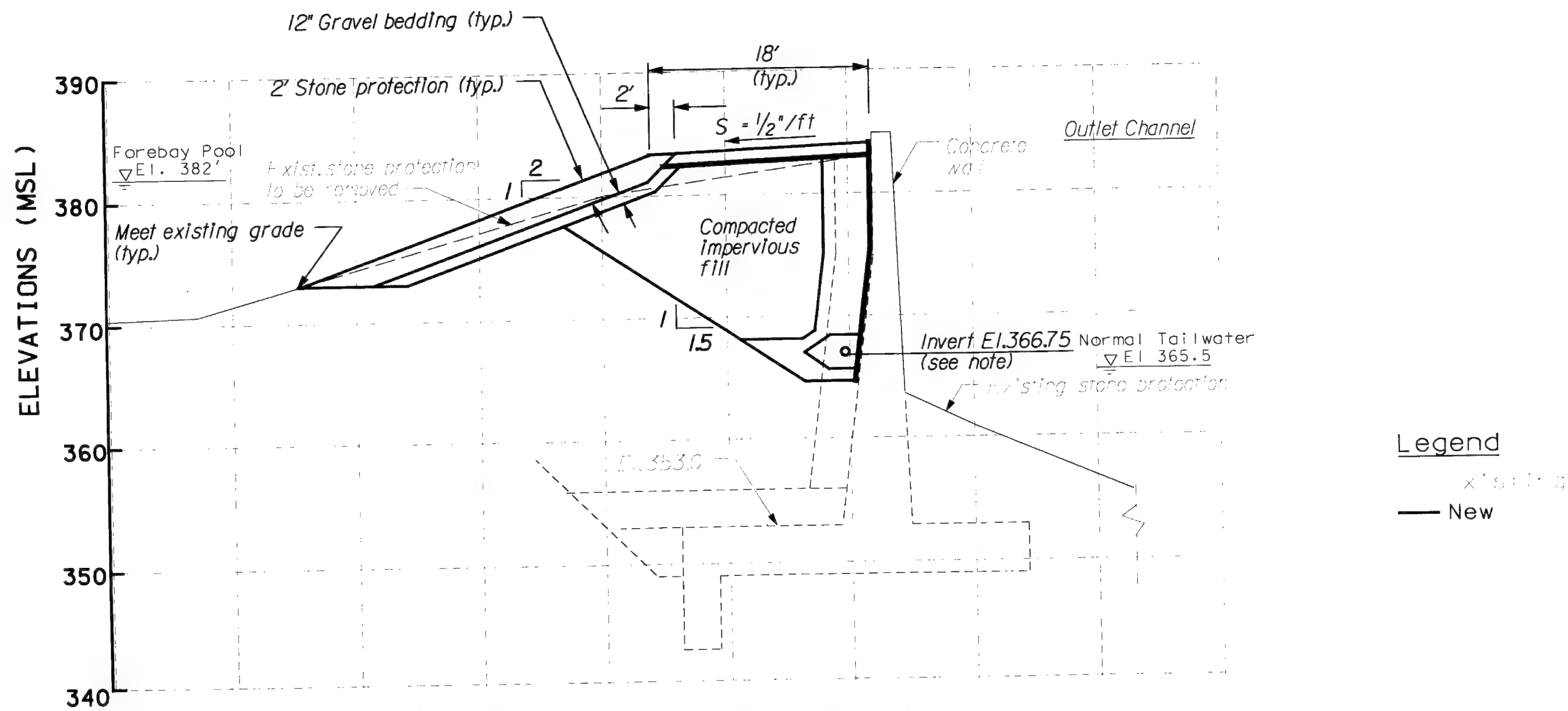
Note:

For 8" perforated pipe installation detail, see Detail A on plate 14

GRAPHIC SCALES:

10 5 0 10 20 FT

DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASSACHUSETTS	
RP (DESIGN BY) MAV (CHECK BY) RP (DRAWN BY)	MERRIMACK VALLEY FLOOD CONTROL HOPKINTON DAM HOPKINTON OUTLET WALL Section C CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 8	SCALE: AS SHOWN DATE: APRIL 1997



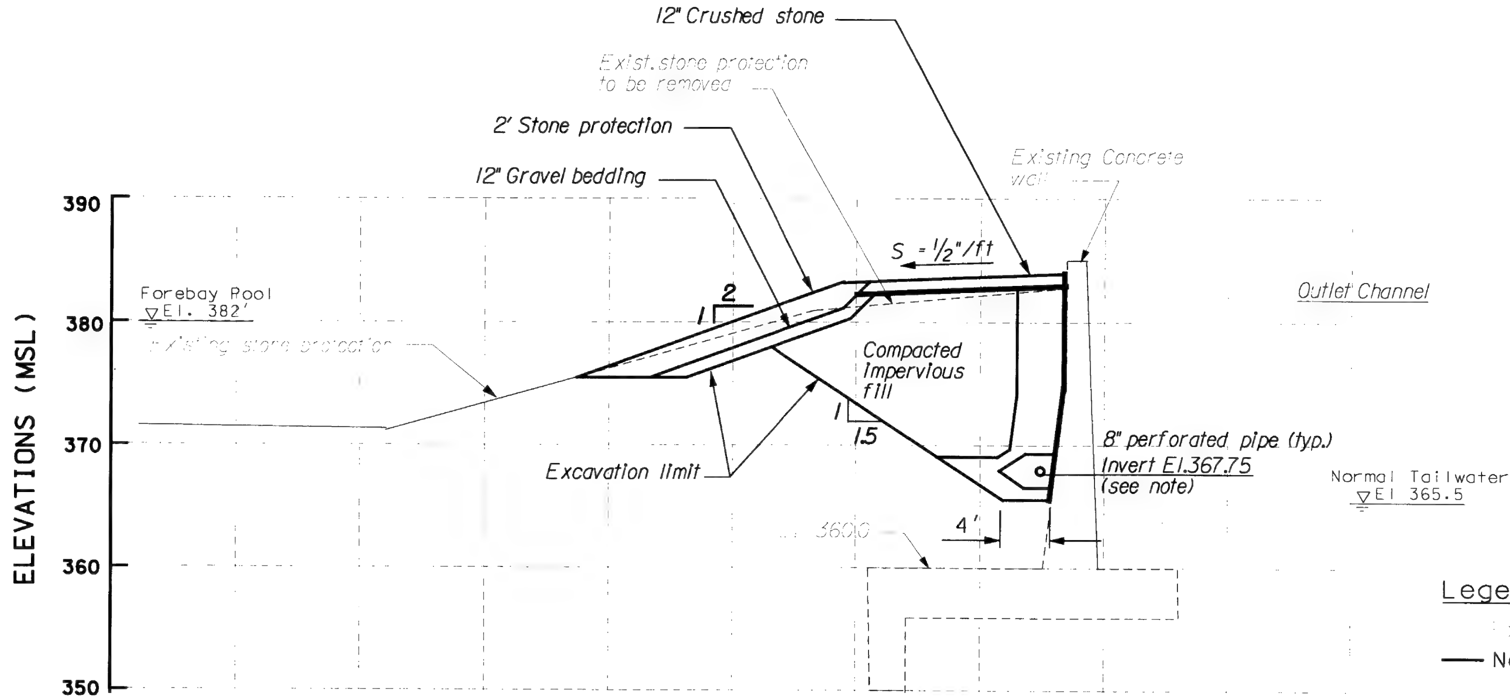
PROPOSED REMEDIAL WORK - SECTION D
STATION 1+90
SCALE: 1"=10'

Note:

For 8" perforated pipe installation detail, see Detail A on plate 14.

GRAPHIC SCALES:

DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASSACHUSETTS	
RP (DESIGN BY) MAV (CHECK BY) RP (DRAWN BY)	MERRIMACK VALLEY FLOOD CONTROL HOPKINTON DAM HOPKINTON OUTLET WALL Section D CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 9	SCALE: AS SHOWN DATE: APRIL 1997



PROPOSED REMEDIAL WORK – SECTION E

STATION 2+25

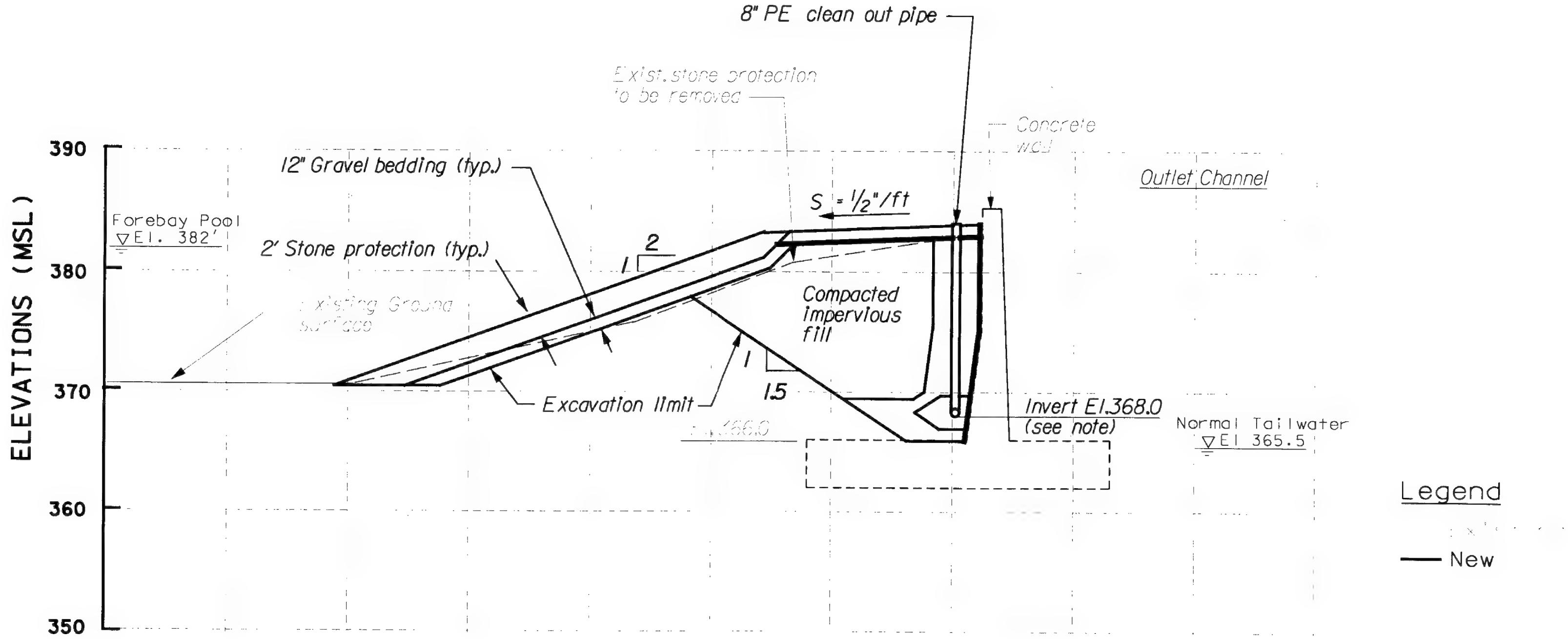
SCALE: 1"=10'

Note:

For 8" perforated pipe installation detail, see Detail A on plate 14.

GRAPHIC SCALES:

DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASSACHUSETTS	
RP (DESIGN BY) MAV (CHECK BY) RP (DRAWN BY)	MERRIMACK VALLEY FLOOD CONTROL HOPKINTON DAM HOPKINTON OUTLET WALL Section E CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 10	SCALE: AS SHOWN DATE: APRIL 1997



PROPOSED REMEDIAL WORK - SECTION F

STATION 2+42

SCALE: 1"=10'

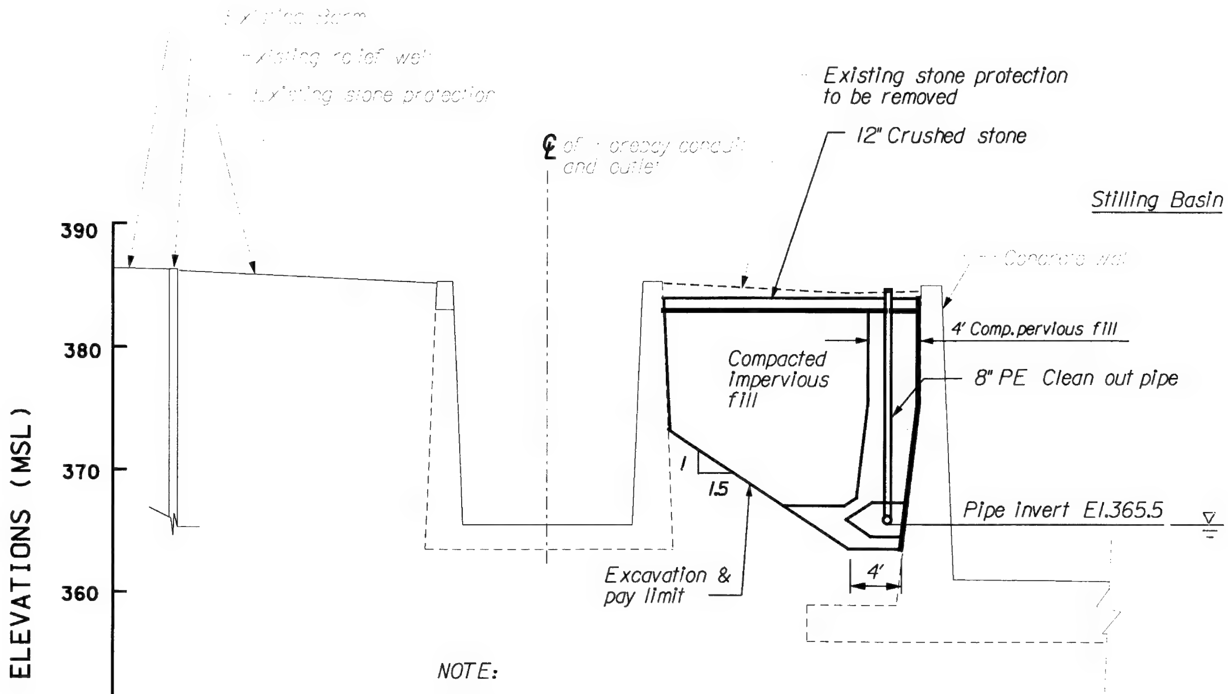
Note:

For 8" perforated pipe installation detail, see Detail A on plate 14.

GRAPHIC SCALES:

10 5 0 10 20FT

DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASSACHUSETTS	
RP (DESIGN BY) MAV (CHECK BY) RP (DRAWN BY)	MERRIMACK VALLEY FLOOD CONTROL HOPKINTON DAM HOPKINTON OUTLET WALL Section F CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 11	SCALE: AS SHOWN DATE: APRIL 1997



NOTE:

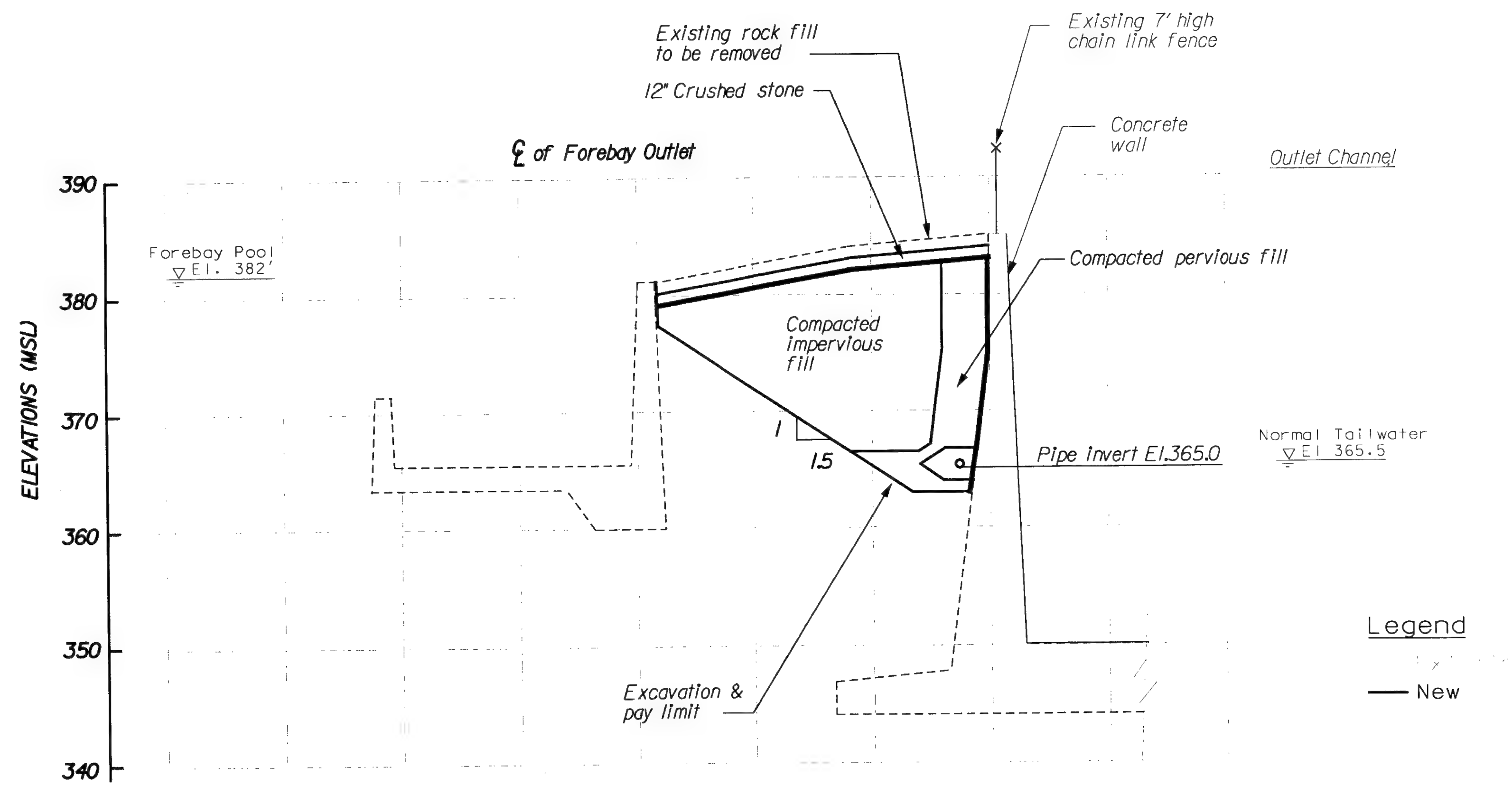
For new 8" perforate pipe section deatial, see Deatial "A".

PROPOSED REMEDIAL WORK – SECTION G
STATION 0+40

SCALE: 1"=10'

GRAPHIC SCALES:

DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASSACHUSETTS	
RP DESIGN BY MAV CHECK BY RP DRAWN BY	MERRIMACK VALLY FLOOD CONTROL HOPKINTON DAM HOPKINTON OUTLET WALL Section G CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 12	SCALE: AS SHOWN DATE: APRIL 1997



PROPOSED REMEDIAL WORK - SECTION H

STATION 0+60

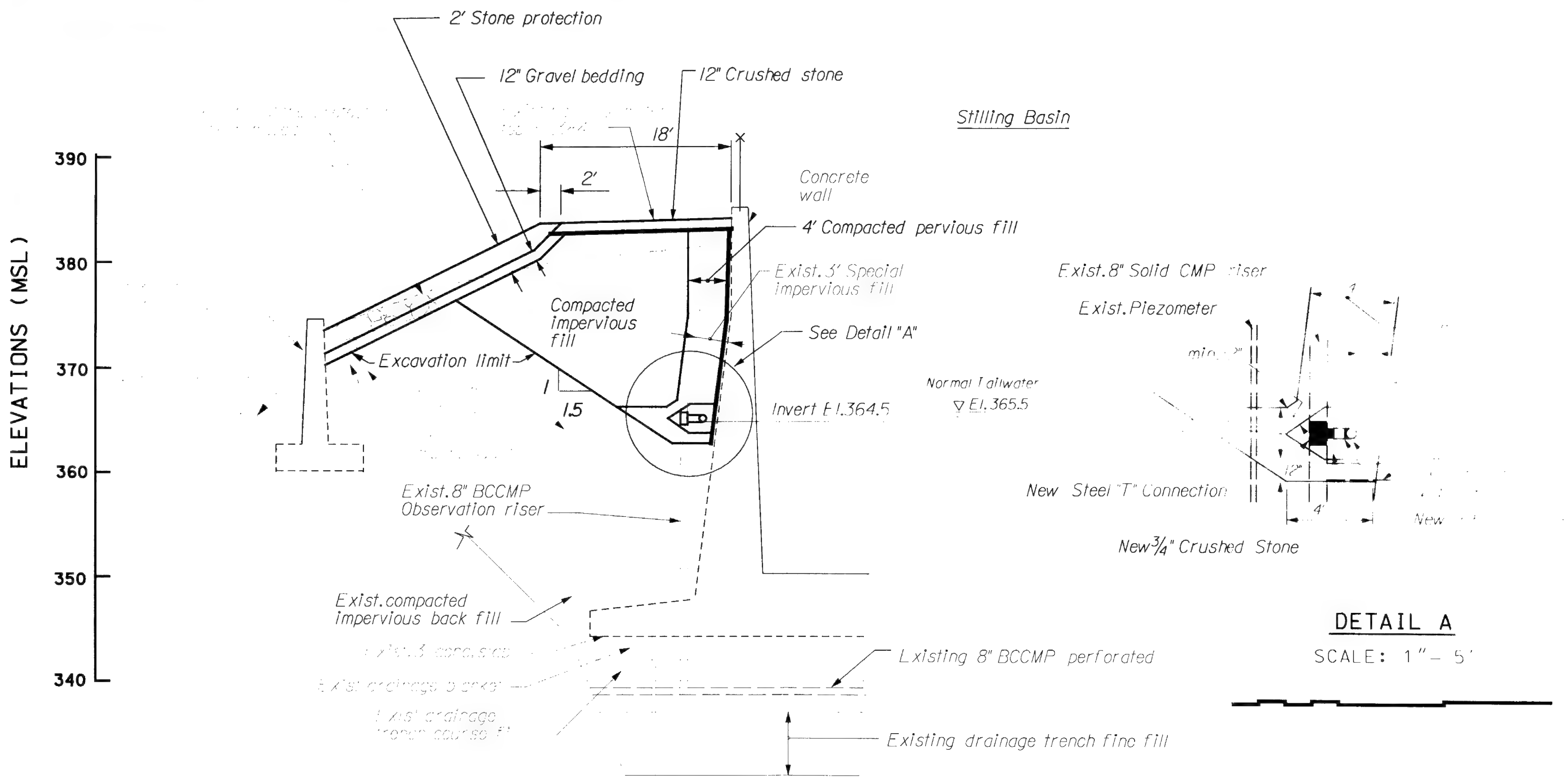
SCALE: 1"=10'

Note:

For 8" perforated pipe installation detail, see Detail A on plate 14

GRAPHIC SCALES:

DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASSACHUSETTS	
DESIGN BY: RP CHECK BY: MAV DRAWN BY: RP	MERRIMACK VALLEY FLOOD CONTROL HOPKINTON DAM HOPKINTON OUTLET WALL Section H CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 13	SCALE: AS SHOWN DATE: APRIL 1997



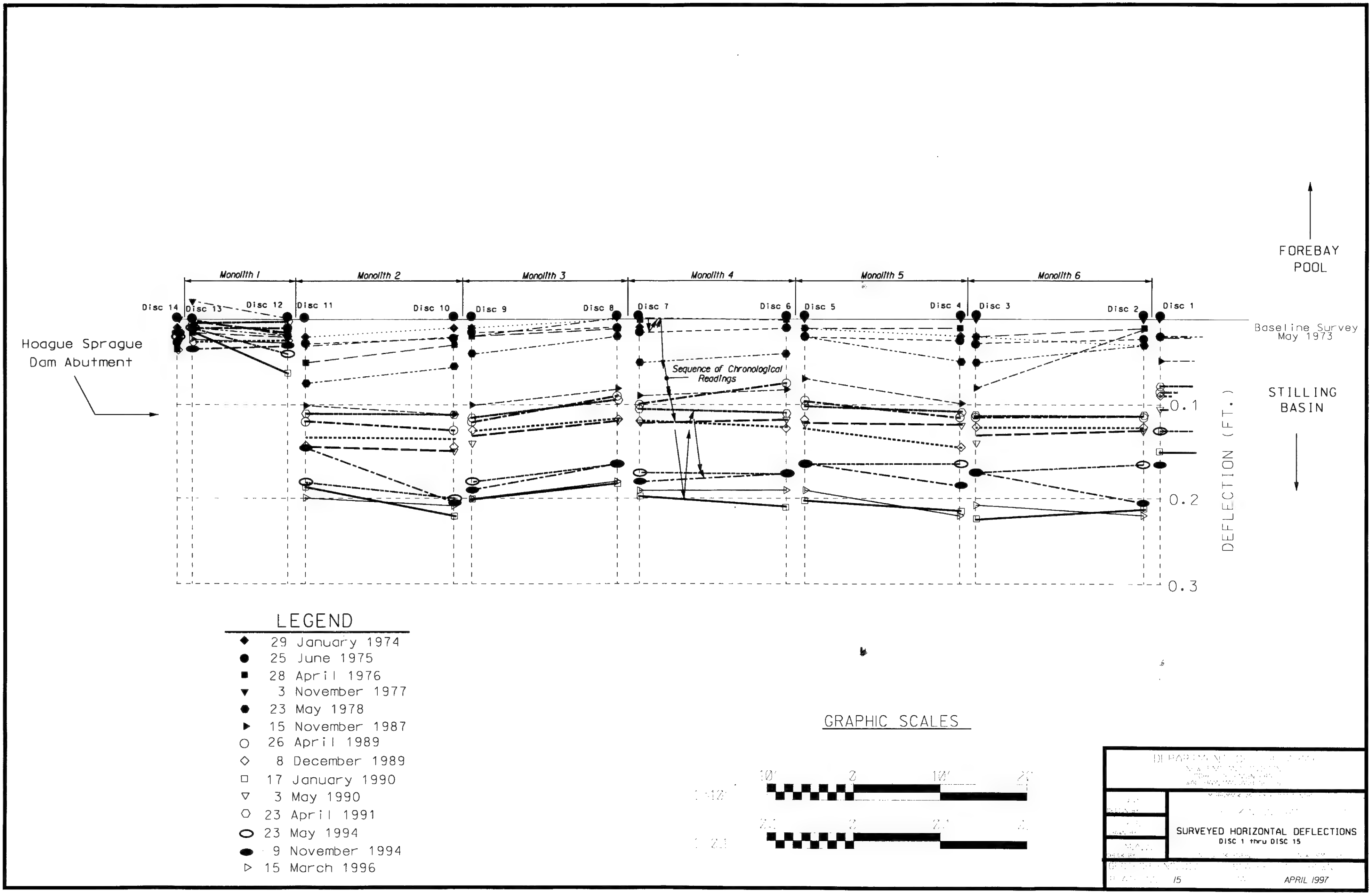
PROPOSED REMEDIAL WORK – SECTION I

STATION 0+86

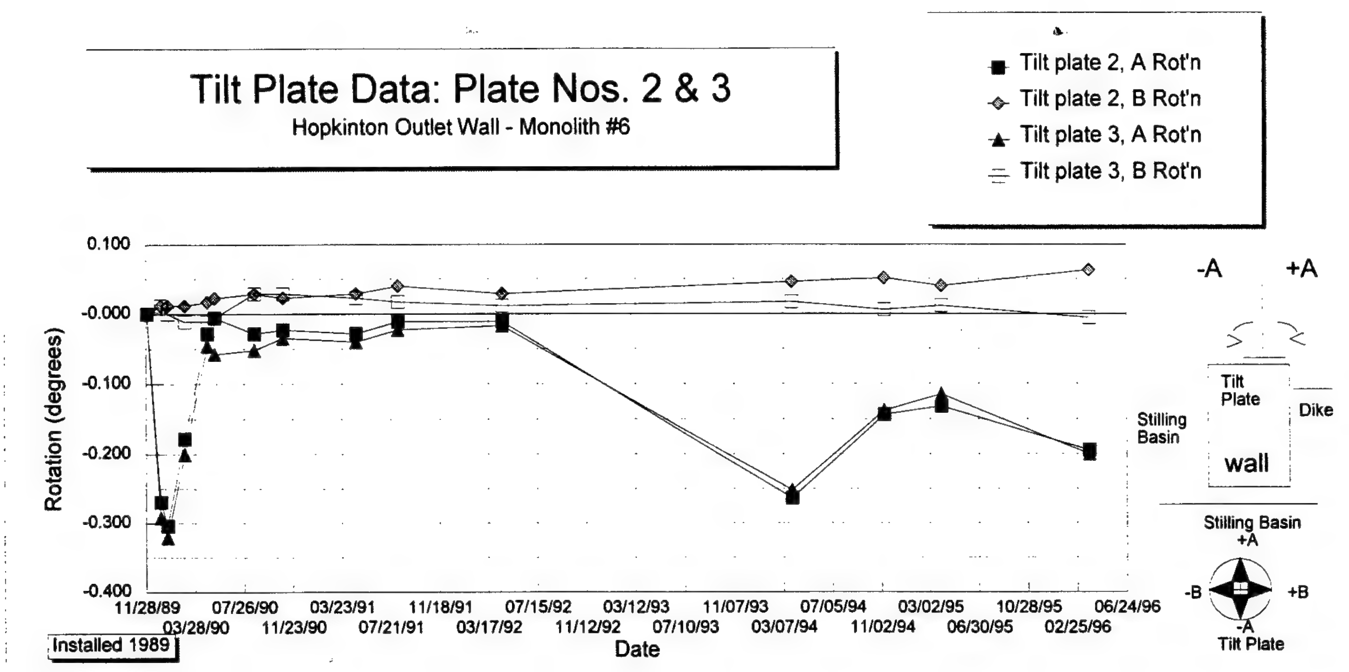
SCALE: 1"=10'

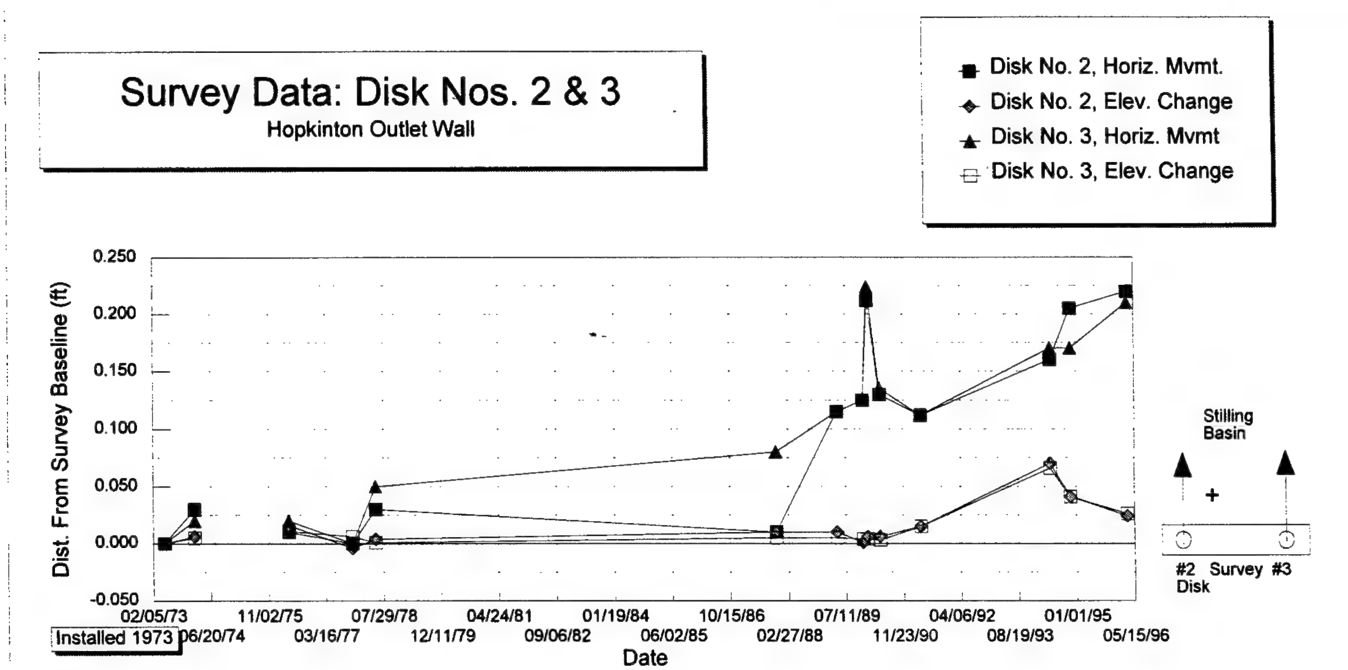
GRAPHIC SCALES:

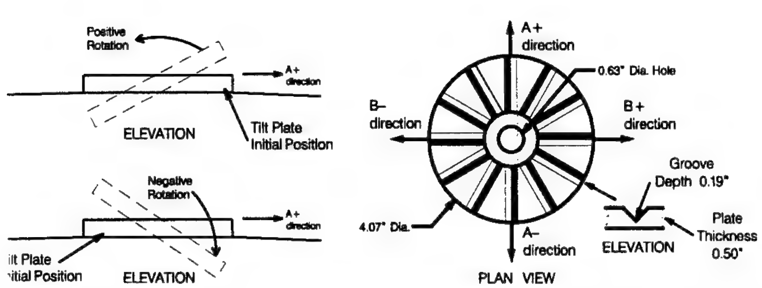
DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASSACHUSETTS	
RP DESIGN BY MAV CHECK BY RP DRAWN BY	MERRIMACK VALLY FLOOD CONTROL HOPKINTON DAM CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 14	SCALE: AS SHOWN DATE: APRIL 199



FOREBAY POOL
STILLING BASIN
Baseline Survey May 1973
Hoague Sprague Dam Abutment
Monolith 1
Monolith 2
Monolith 3
Monolith 4
Monolith 5
Monolith 6
Disc 14
Disc 13
Disc 12
Disc 11
Disc 10
Disc 9
Disc 8
Disc 7
Disc 6
Disc 5
Disc 4
Disc 3
Disc 2
Disc 1
Sequence of Chronological Readings
DEFLECTION (FT.)
0.1
0.2
0.3
LEGEND
29 January 1974
25 June 1975
28 April 1976
3 November 1977
23 May 1978
15 November 1987
26 April 1989
8 December 1989
17 January 1990
3 May 1990
23 April 1991
23 May 1994
9 November 1994
15 March 1996
GRAPHIC SCALES
SURVEYED HORIZONTAL DEFLECTIONS
DISC 1 thru DISC 15
15
APRIL 1997





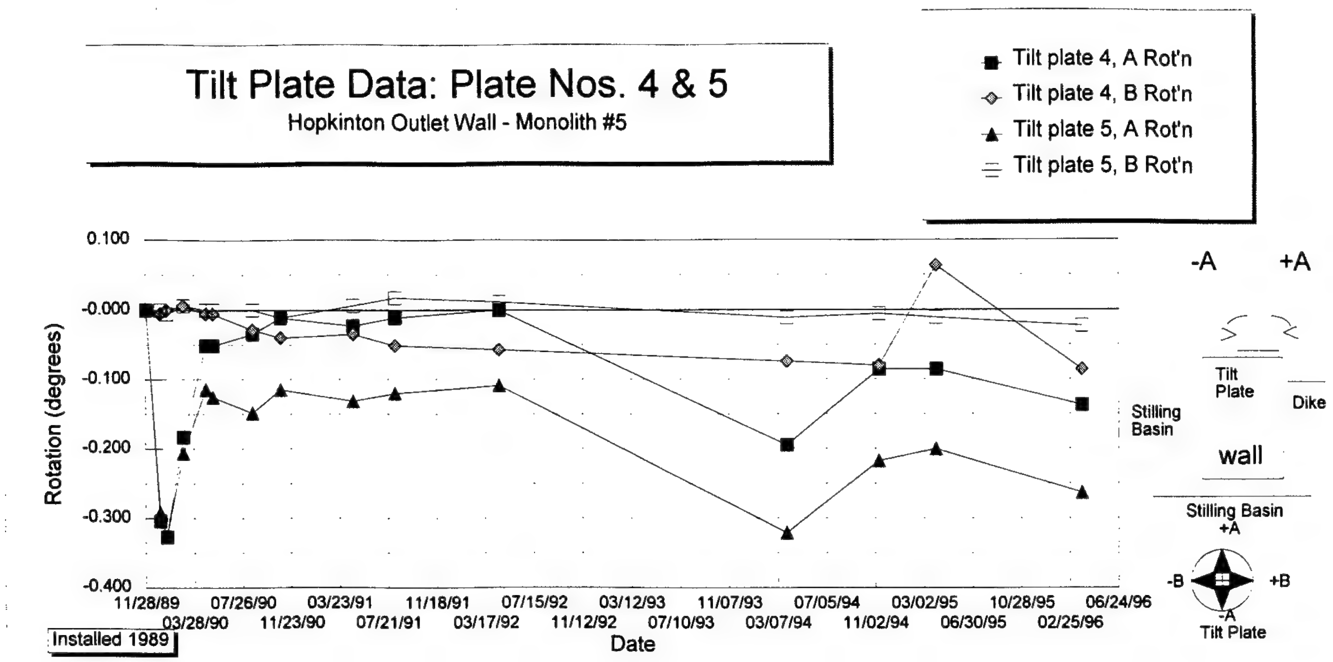


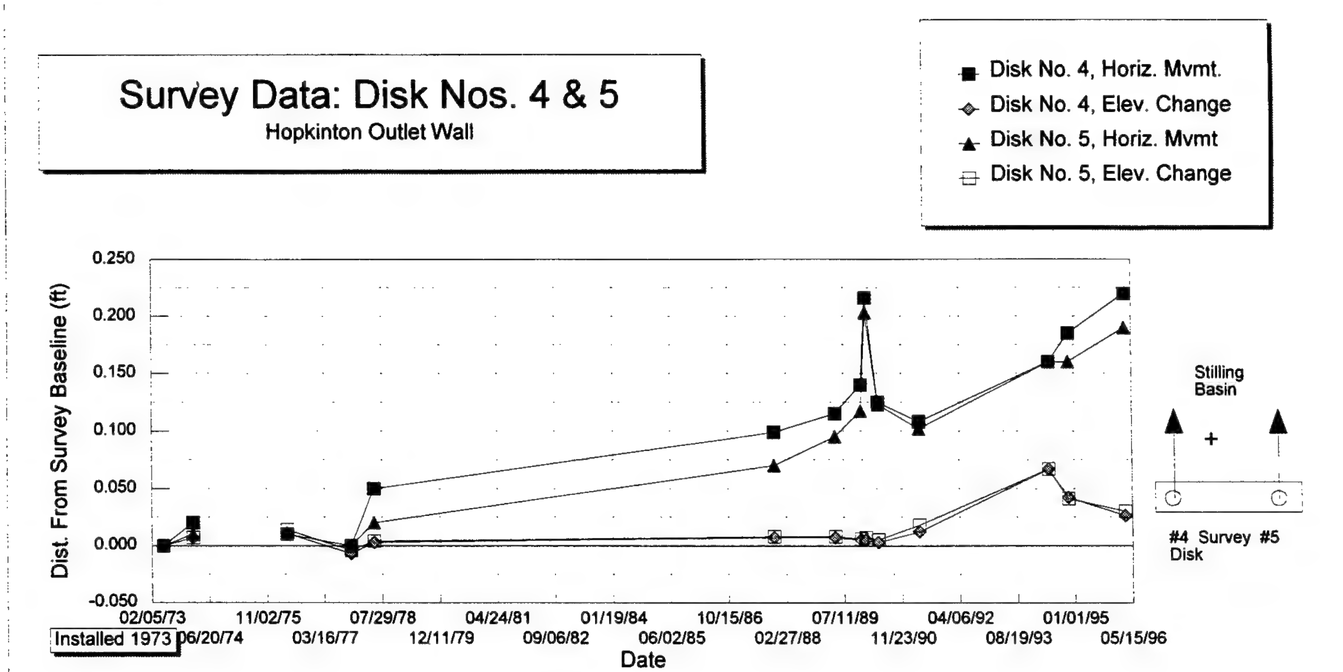
TYPICAL TILT PLATE

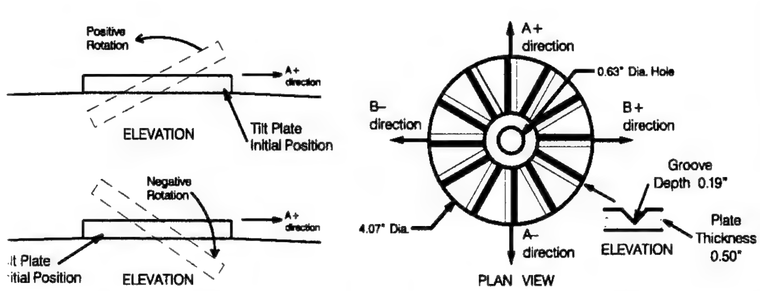
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

RP DESIGN BY	MERRIMACK VALLEY FLOOD CONTROL HOPKINTON DAM
MAV CHECK BY	TILT PLATE AND SURVEY DATA 2 & 3
RP DRAWN BY	CONTOOCOOK RIVER NEW HAMPSHIRE

GEOTECH. ENG. DIV.	SCALE: NO SCALE
PLATE NO. 16	DATE: APRIL 1997



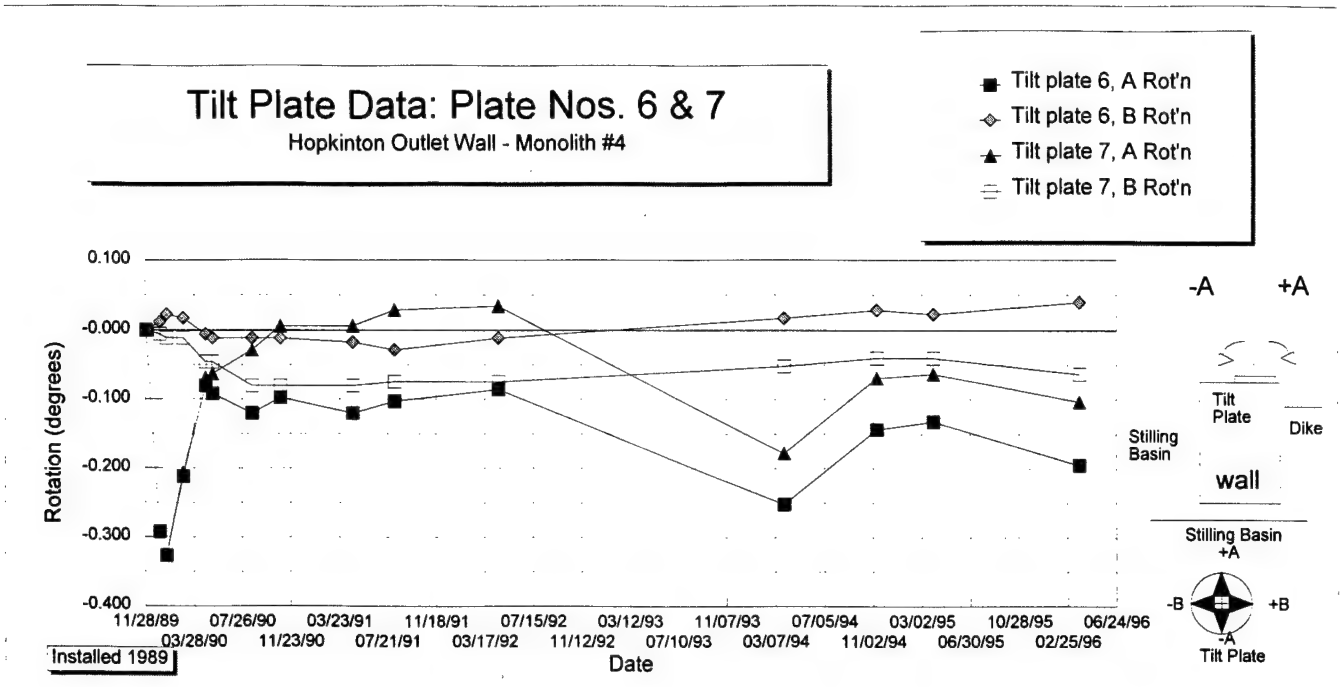


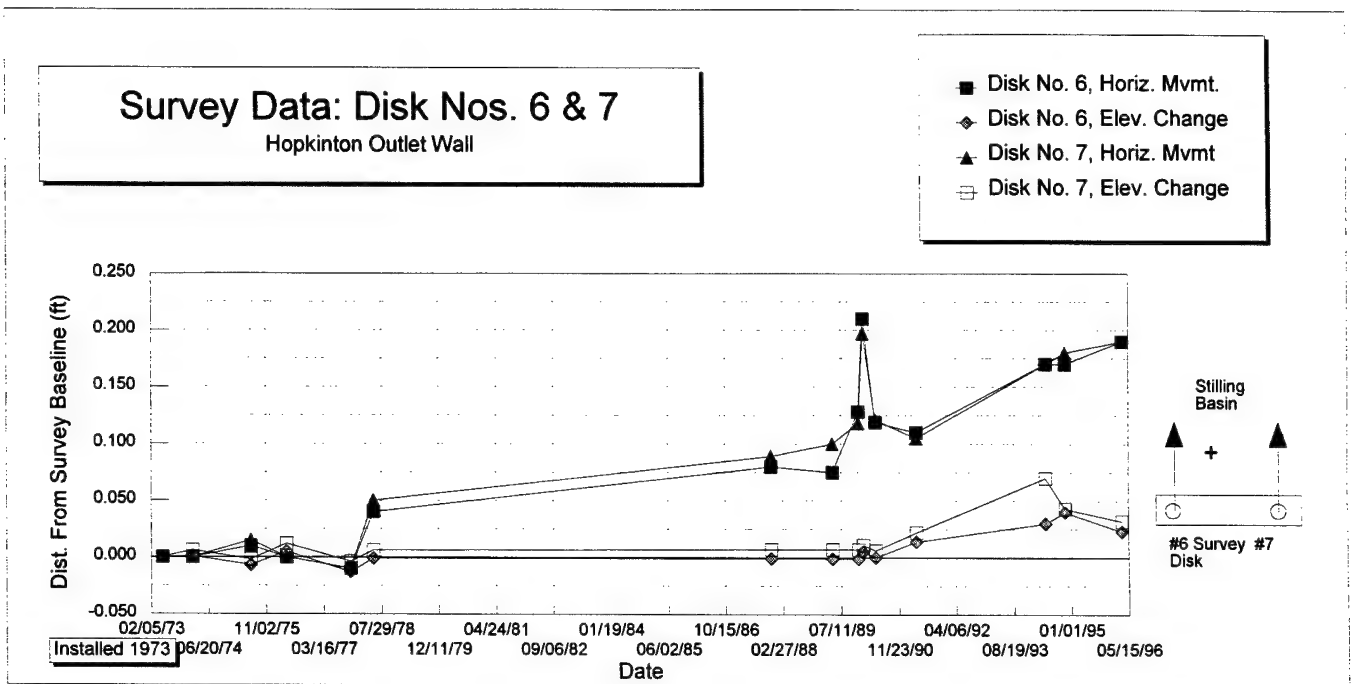


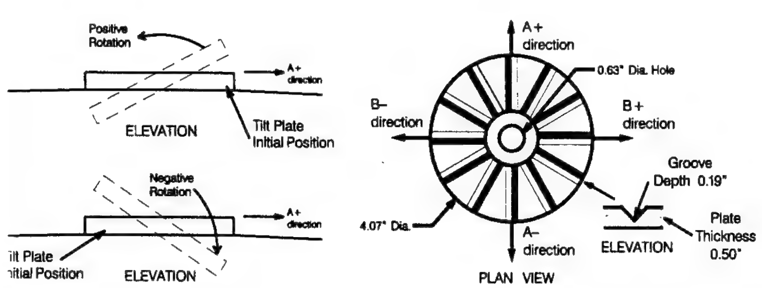
TYPICAL TILT PLATE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

RP DESIGN BY	MERRIMACK VALLEY FLOOD CONTROL HOPKINTON DAM TILT PLATE AND SURVEY DATA 4 & 5 CONTOOCOOK RIVER NEW HAMPSHIRE
MAV CHECK BY	
RP DRAWN BY	
GEOTECH. ENG. DIV. PLATE NO. 17	SCALE: NO SCALE DATE: APRIL 1997

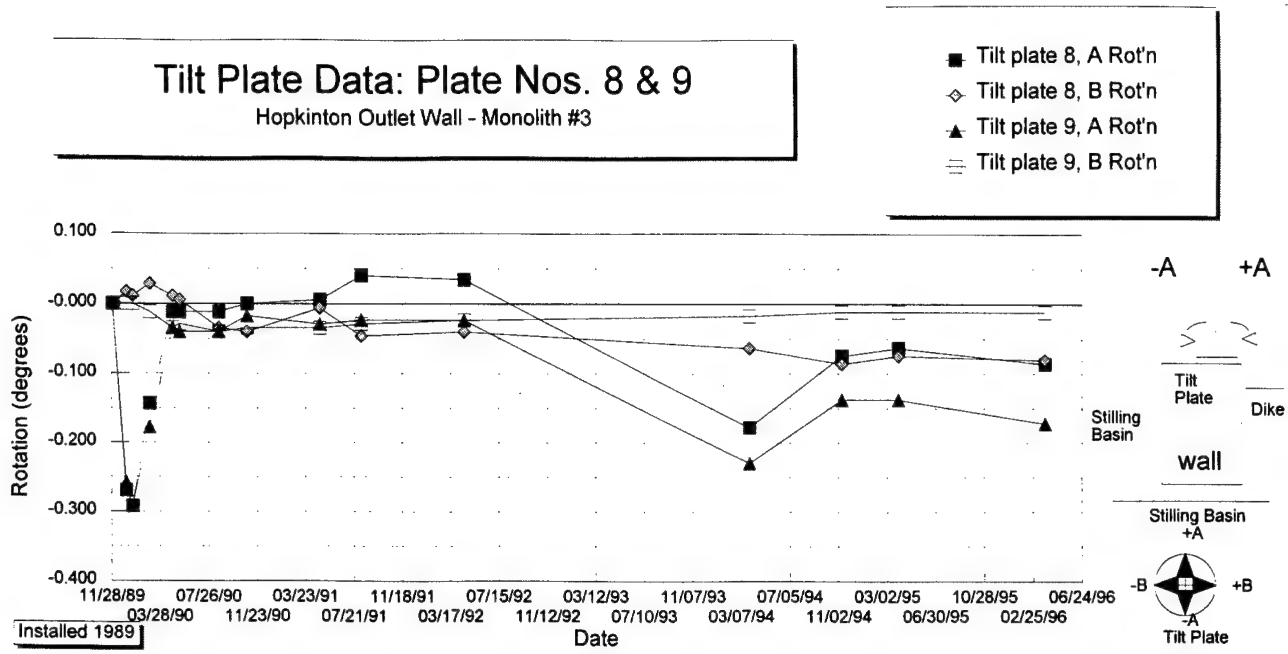


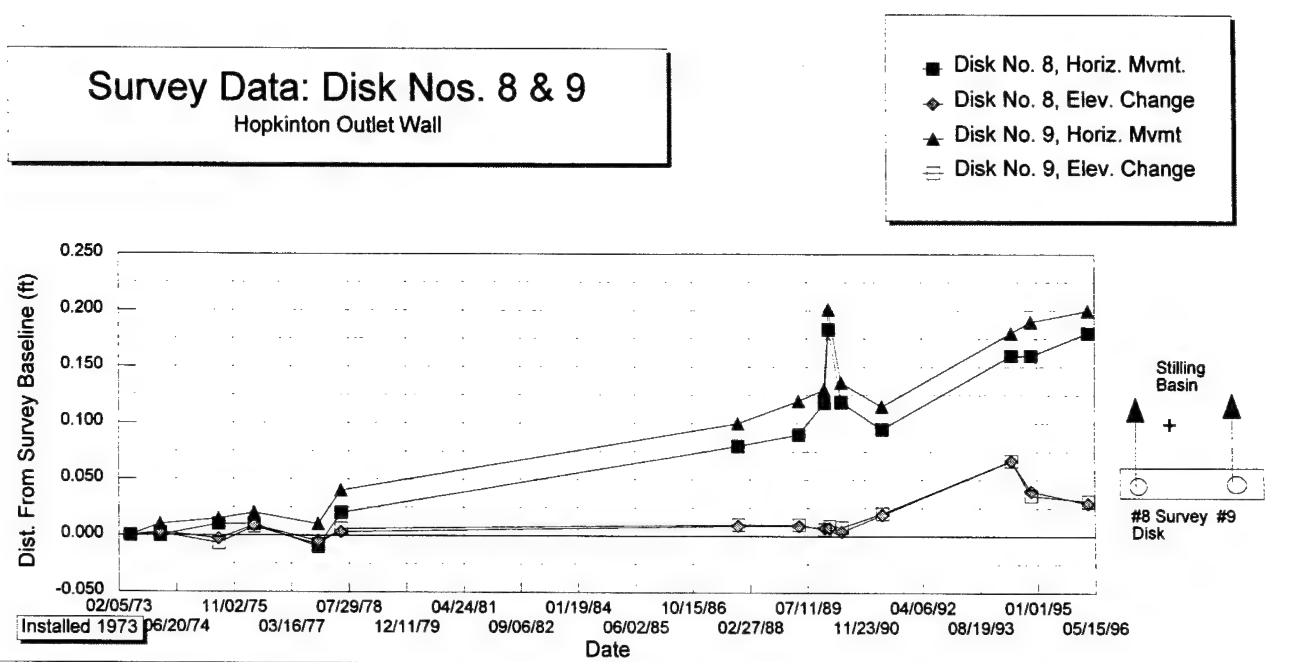


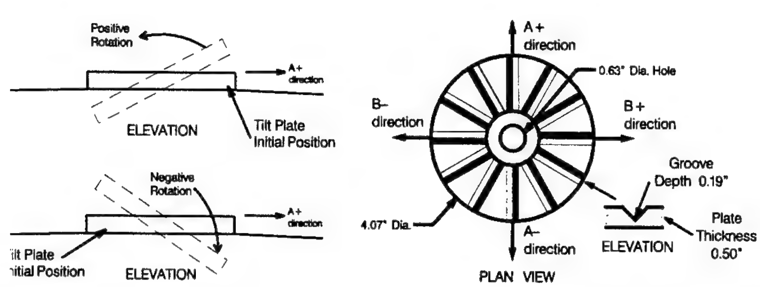


TYPICAL TILT PLATE

DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASSACHUSETTS	
RP DESIGN BY	MERRIMACK VALLEY FLOOD CONTROL HOPKINTON DAM TILT PLATE AND SURVEY DATA 6 & 7
MAV CHECK BY	
RP DRAWN BY	CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV.	SCALE: NO SCALE
PLATE NO. 18	DATE: APRIL 1997







TYPICAL TILT PLATE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

RP
DESIGN BY

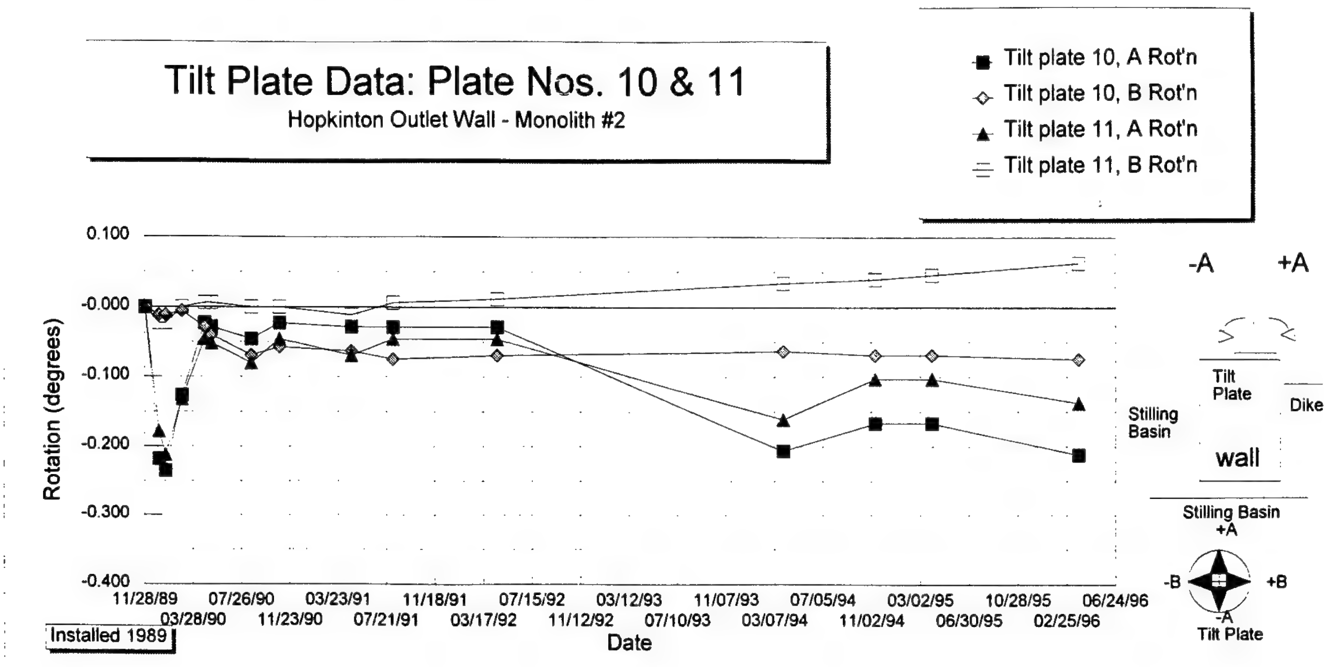
MAV
CHECK BY

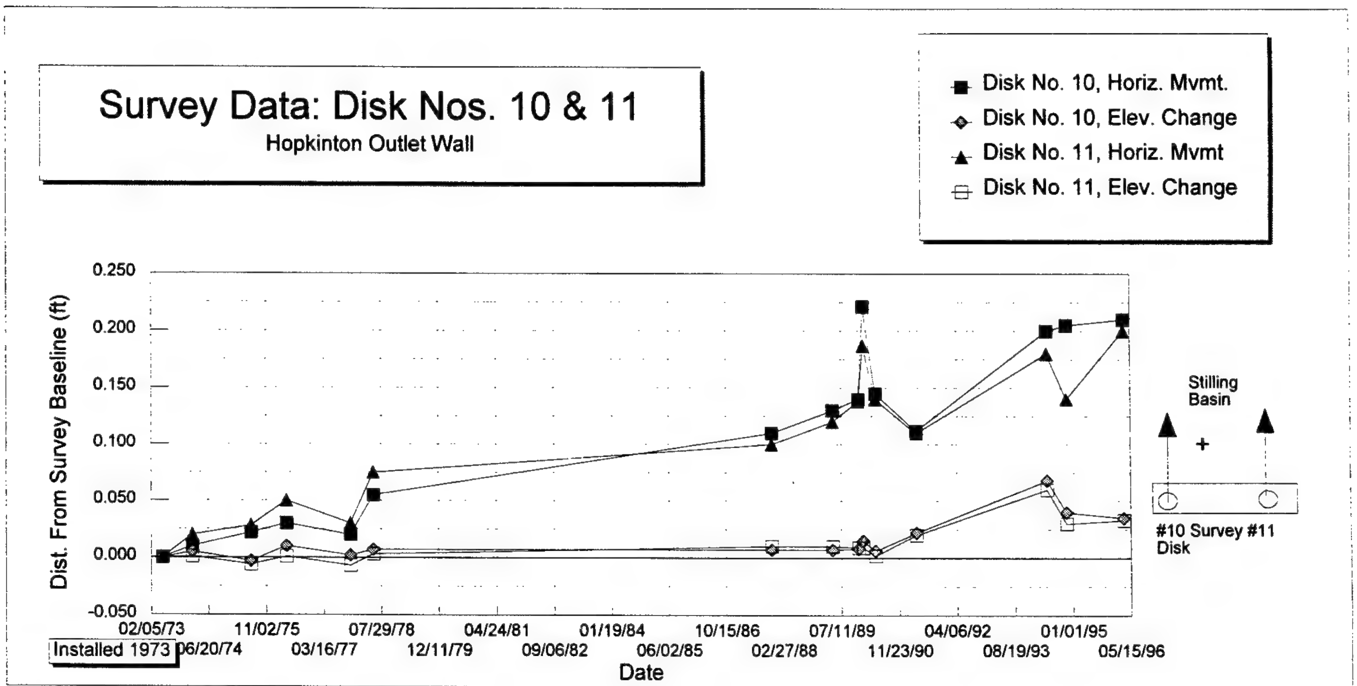
RP
DRAWN BY

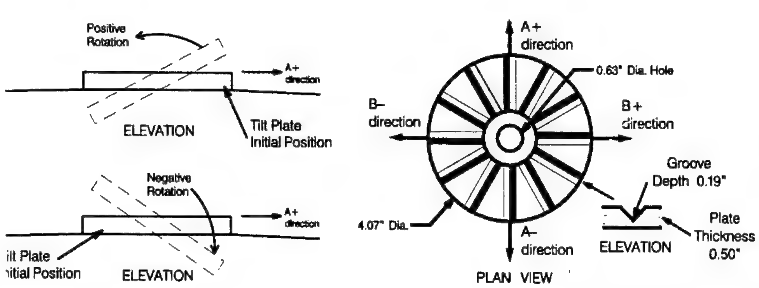
MERRIMACK VALLEY FLOOD CONTROL
HOPKINTON DAM
TILT PLATE AND SURVEY DATA
8 & 9
CONTOOCOOK RIVER NEW HAMPSHIRE

GEOTECH. ENG. DIV.
PLATE NO. 19

SCALE: NO SCALE
DATE: APRIL 1997



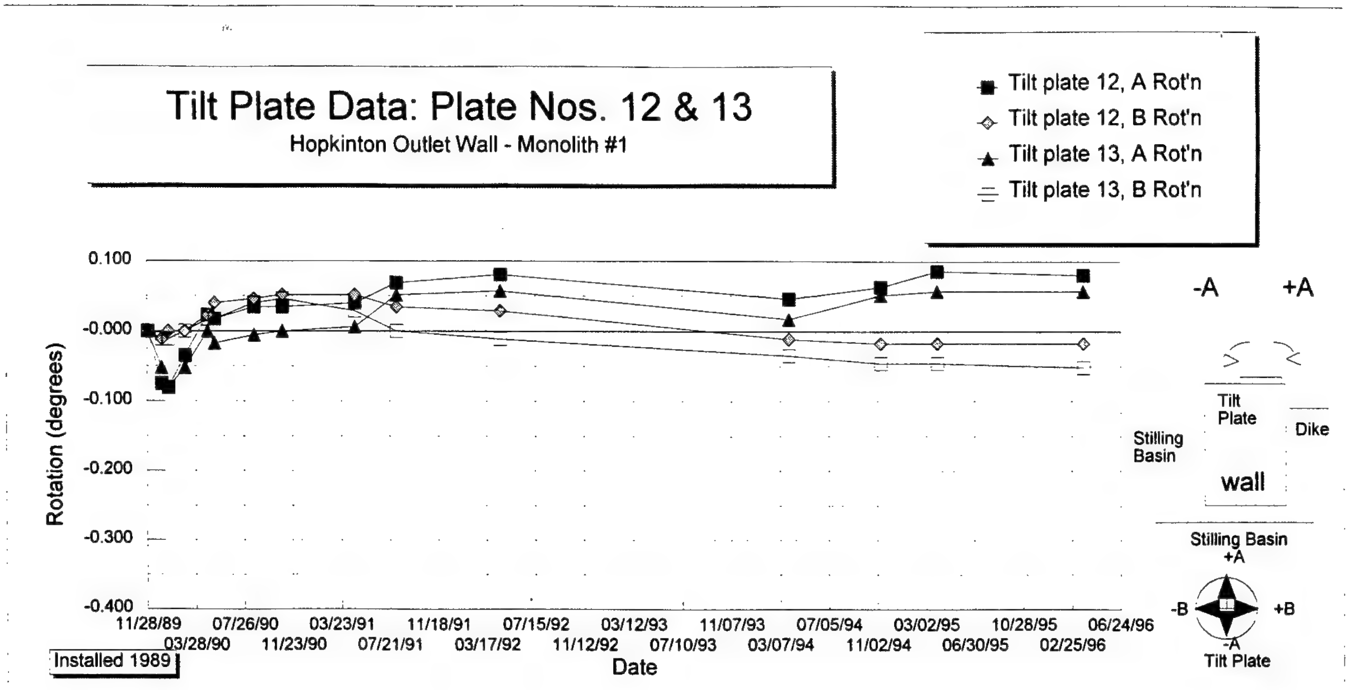


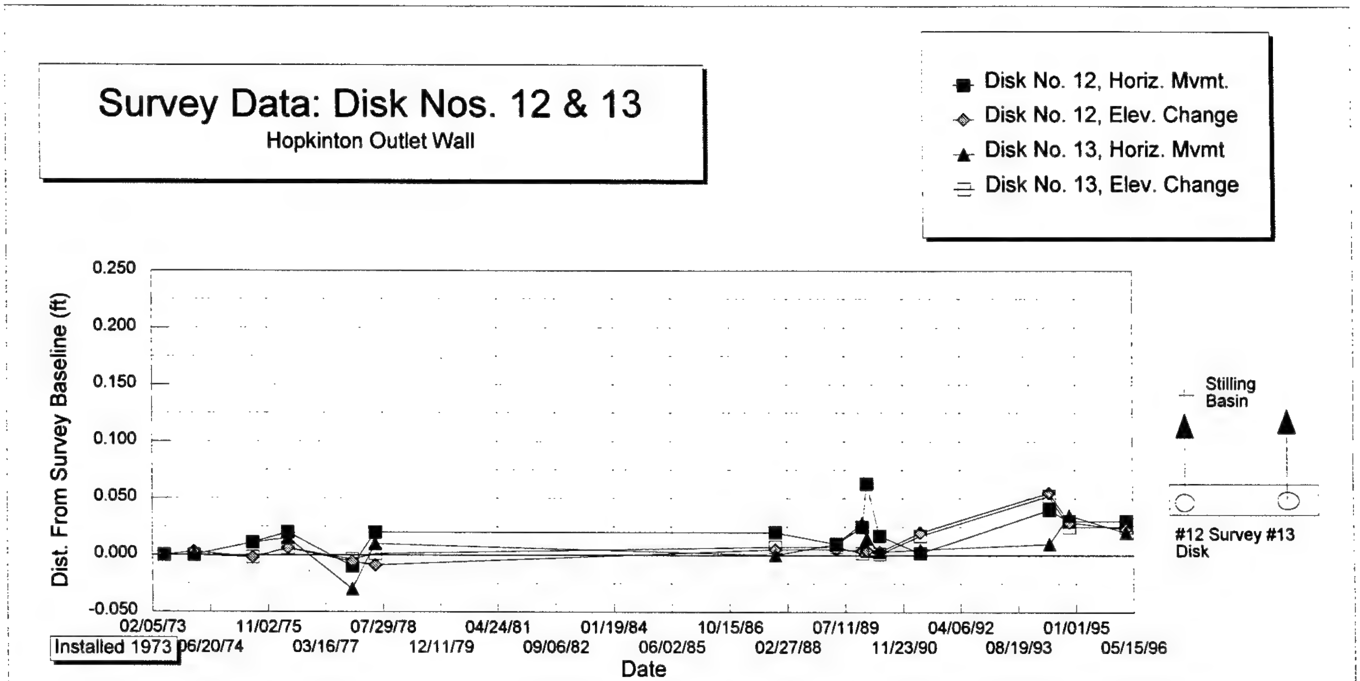


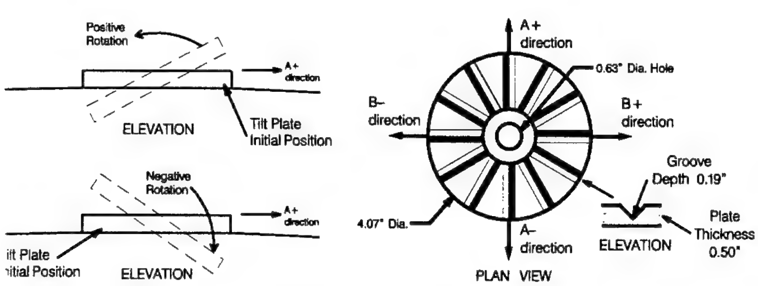
TYPICAL TILT PLATE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

RP DESIGN BY	MERRIMACK VALLEY FLOOD CONTROL HOPKINTON DAM
MAV CHECK BY	TILT PLATE AND SURVEY DATA 10 & 11
RP DRAWN BY	CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 20	SCALE: NO SCALE DATE: APRIL 1997

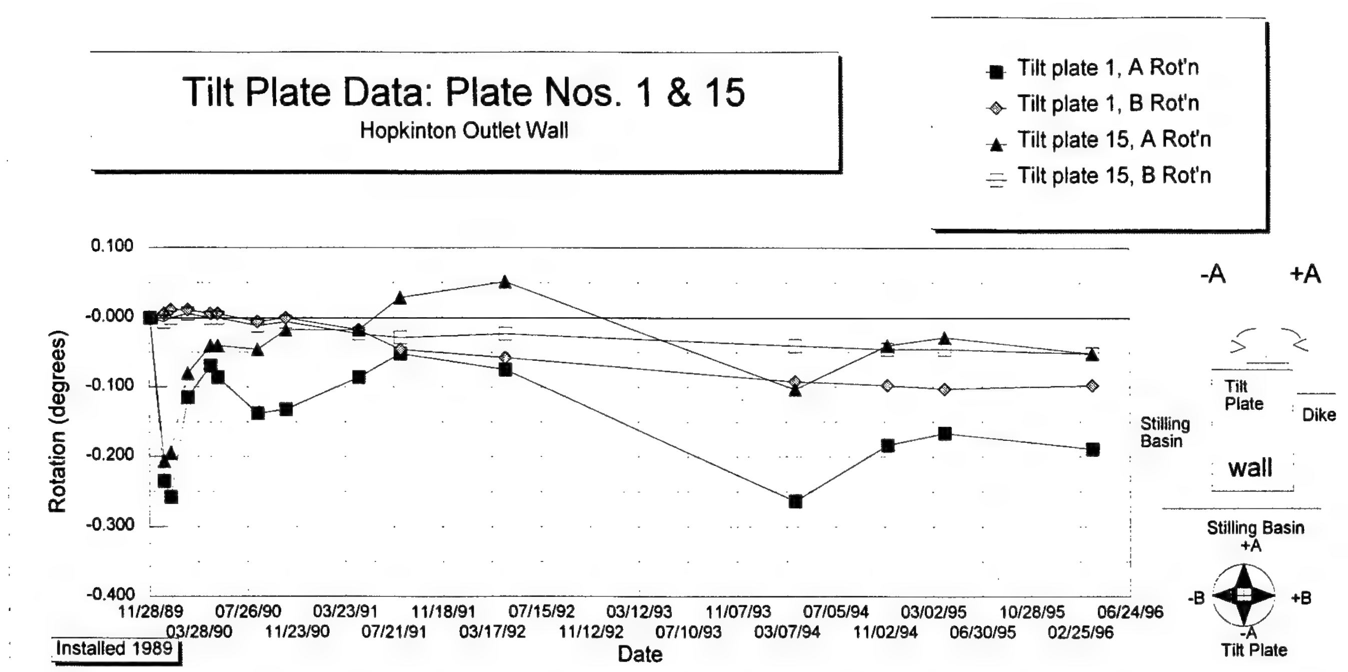


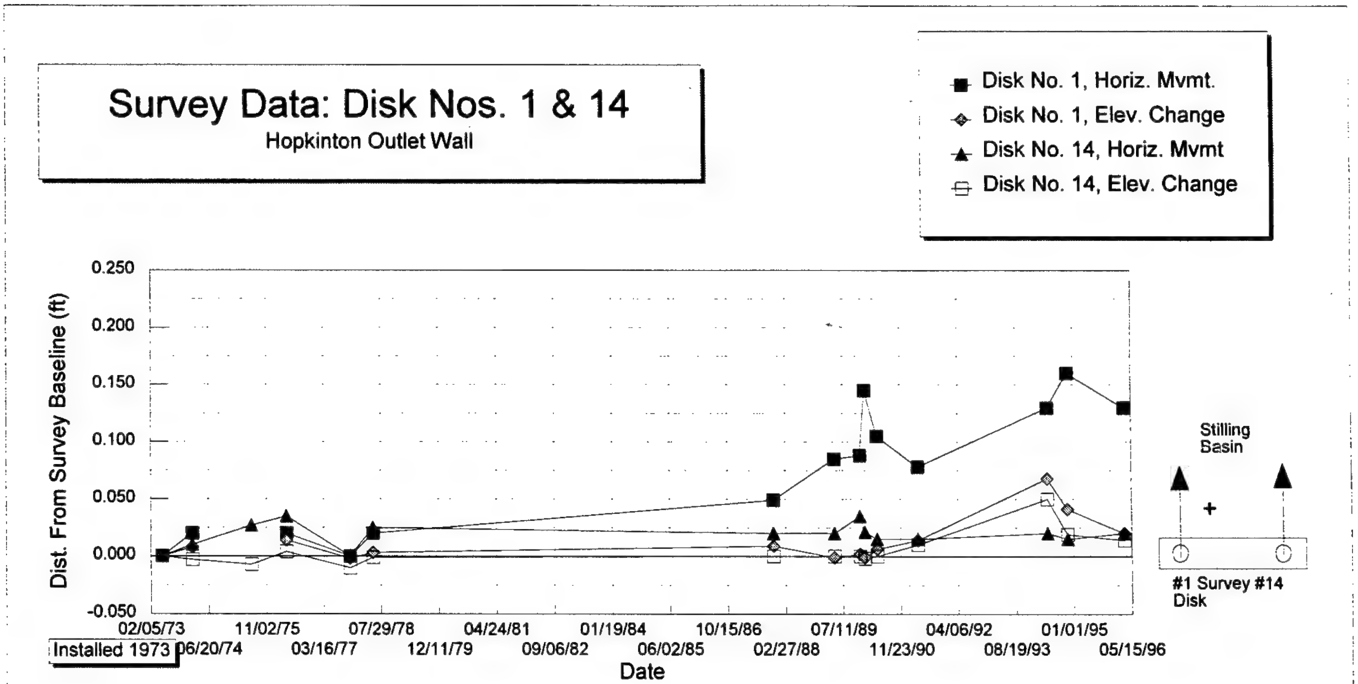


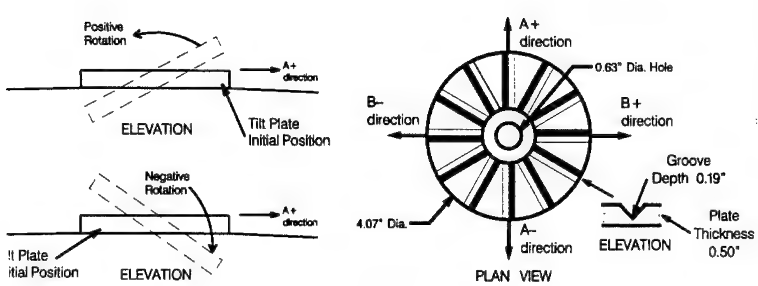


TYPICAL TILT PLATE

DEPARTMENT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MASSACHUSETTS	
RP DESIGN BY MAV CHECK BY RP DRAWN BY	MERRIMACK VALLEY FLOOD CONTROL HOPKINTON DAM TILT PLATE AND SURVEY DATA 12 & 13 CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 21	SCALE: NO SCALE DATE: APRIL 1997







TYPICAL TILT PLATE

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

RP DESIGN BY	MERRIMACK VALLEY FLOOD CONTROL
MAV CHECK BY	HOPKINTON DAM TILT PLATE DATA: 1 & 15 SURVEY DATA: 1 & 14
RP DRAWN BY	CONTOOCOOK RIVER NEW HAMPSHIRE
GEOTECH. ENG. DIV. PLATE NO. 22	SCALE: NO SCALE DATE: APRIL 1997

APPENDIX A -- STRUCTURAL ANALYSIS

HOPKINTON RETAINING WALL - STRUCTURAL ANALYSIS

PURPOSE AND SCOPE

Frost loads on the east outlet retaining walls were calculated from the measured deflections and the assumptions of limits of frost loading on the walls . Forces acting on representative wall sections were analyzed to determine the theoretical deflection of the walls due to frost and soil loadings. Analysis for overturning and bearing pressures was performed utilizing values of soil, wall and water pressures.

ASSUMPTIONS

CONCRETE
Compressive Strength of Concrete, $f'_c = 3000$ psi
Modulus of Elasticity of Concrete, $E_c = 3.12 \times 10^6$ psi

STEEL
Yield Strength of Steel, $f_y = 60{,}000$ psi
Development of reinforcement at base into stem of wall.

DEAD LOADS

Rock	135 P.C.F.
Impervious Fill	140 P.C.F.
Concrete	150 P.C.F.
Gravel	150 P.C.F.

PROCEDURE

Calculations were based on actual design information obtained from the existing retaining walls from project drawings and loadings, deflections and soil properties supplied by the Geotechnical Engineering Division.

Maximum and frost deflections of the east walls, as shown on Geotechnical Plate No. 2 - Outlet Wall Plan, were used to back calculate the frost force acting on the walls within the frost zone specified by Plates 3 to 6 - Earth Pressure Diagrams.

Active and pore pressures per unit length of the wall were determined in order to assess soil pressures on the walls. Moments due to active and pore pressures (Mact) were calculated for the full depth of each wall at 0.5 ft intervals. The theoretical moment capacity (Mu) was calculated based upon the available information about the concrete properties and the reinforcement size and location as obtained from the record drawings for the existing project. The moments due to the frost loadings (Mice) were determined from the previously calculated frost forces and their area of influence. Cracking moments (Mcr) were calculated for the walls

based on available geometric information of the existing wall sections. If the moment due to the frost loadings plus the moment due to the earth pressures on the wall were greater than the cracking moment, then it was assumed that the section of wall is cracked at that location. Allowable moment due to frost loadings (Mall ice) on the wall is the difference between the theoretical moment capacity and actual moment due to active soil and pore pressures on the wall. Deflections at each wall interval due to frost and earth pressure were calculated and summed for a total theoretical deflection of the wall due to those forces.

To check the stability of the retaining walls, overturning analyses were performed. Overturning analysis included the calculations of pressures exerting overturning moments on the walls. Horizontal overturning forces included the active soil (Pa) and the frost pressures (Pice). The vertical overturning pressures were caused by uplift forces (U1). For calculation of the resisting moments, the weight of the soil above the heel and the weight of the concrete were calculated. The resisting forces include the horizontal water pressure on the toe side of the walls (Pw1) and the vertical forces exerted by the weight of the walls (C1, 2, 3, 4) and rock, gravel and soil behind them (WS).

The vertical pressures as transmitted to the soil by the base slab of the retaining walls were determined for comparison to the ultimate bearing capacity of the soil. Bearing pressure left and right are the maximum and minimum pressures occurring at the toe and heel sections, respectively.

SUMMARY OF RESULTS

Frost loads for each wall were calculated from the measured deflections of the retaining walls. Theoretical deflections for full depth of the walls determined from the calculated values of frost load generally compare well to the observed values and are summarized as follows:

	Frost Load (plf)	Deflections due to Frost (inch)	Deflections due to Frost and Soil Pressure (inch)	Measured Deflections due to Frost (inch)	Measured Deflections due to Frost and Soil Pressure (inch)
Wall A	615	1.19	2.48	0.91-1.19	2.44-2.69
Wall B	620	1.10	2.20	0.78-0.97	2.20-2.65
Wall C	200	0.45	1.70	0.59	2.24
Stilling Basin Wall	620	0.81	1.65	0.68	1.74

The value of frost load calculated for Wall C was comparatively low. The calculated actual moment exceeded the ultimate moment at elevation 360.0 at Wall C. The steel reinforcement size and the quantities obtained from the project drawings for this section are presumed incorrect and would result in the values obtained.

Resisting moments exceed overturning moments with the following factors of safety with respect to overturning:

	Factor of Safety
Wall A	1.58
Wall B	1.55
Wall C	1.98

The usual minimum desirable value for the factor of safety with respect to overturning is 1.5 to 2.0.

The maximum and minimum bearing pressures for the toe and heel sections are as follows:

	q_{max} (ksf)	q_{min} (ksf)
Wall A	4.45	0.61
Wall B	4.94	0.02
Wall C	3.35	1.15

Sample calculations, spreadsheets and summaries of all work are attached.

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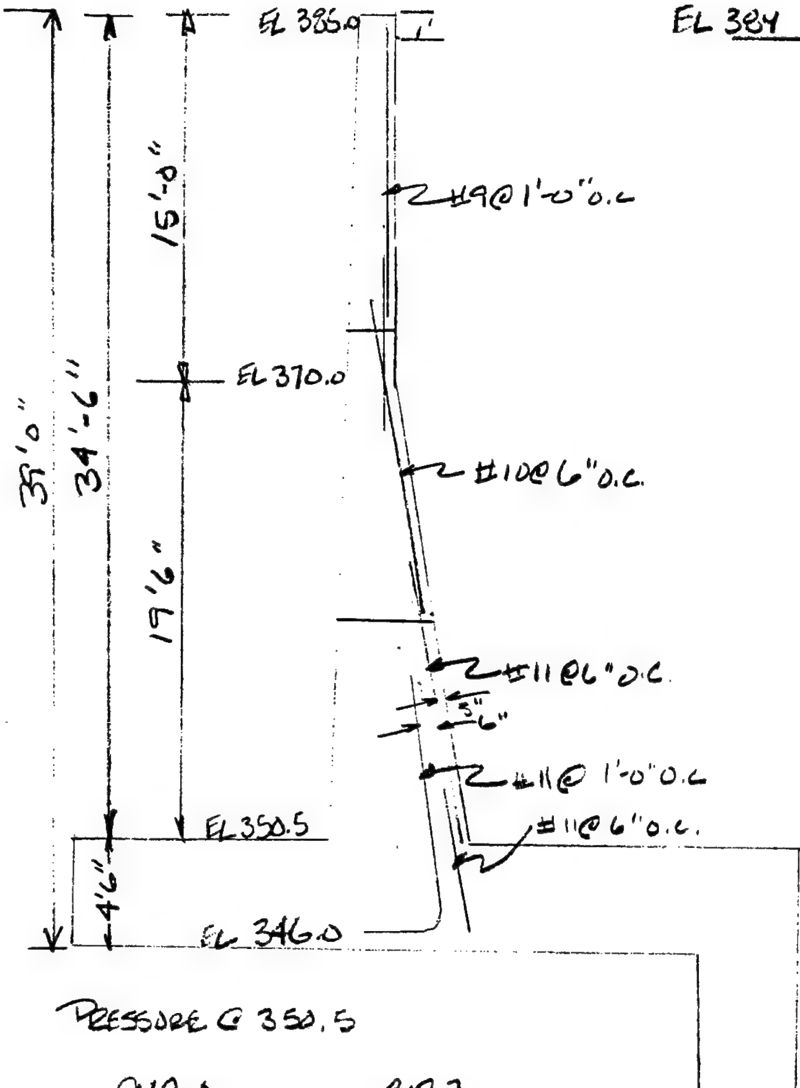
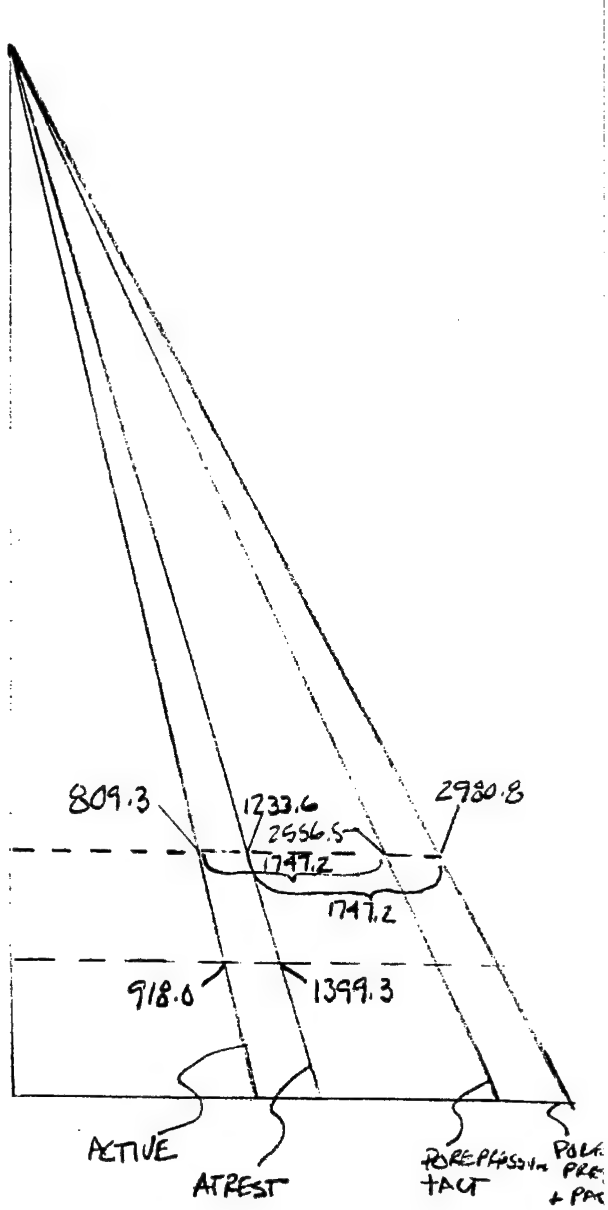
SUBJECT HOPKINTON FACT RETAINING WALL
COMPUTATION BACKUP CALCULATIONS
COMPUTED BY NAD CHECKED BY JDC DATE 1/14/94

WALL A SEC B-B





PRESSURE @ 350.5

A $\frac{918.0}{38} \times 33.5 = 809.3$

R $\frac{1399}{38} \times 33.5 = 1233.6$

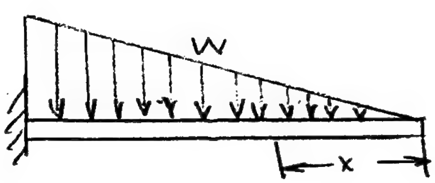
ACTIVE + PORE PRESSURE = 809.3 + 1747.2 = 2556.5 lb/ft
AT REST + PORE PRESSURE = 1233.6 + 1747.2 = 2980.8 lb/ft.

SUBJECT HOPKINTON EAST RETAINING WALL
COMPUTATION BACKUP CALCULATIONS
COMPUTED BY MAD CHECKED BY JAC DATE 1/14/94

USE ACTIVE PRESSURE DUE TO MOVEMENT OF THE WALL

- CALCULATE MOMENT DUE TO ACTIVE PRESSURE + PORE PRESSURE
- SEGMENT WALL INTO 0.5' INTERVALS

ACTIVE + PORE PRESSURE = 2556.5 lb/ft



$$W = \frac{w\ell}{2} = \frac{2556.5(33.5)}{2} = 42821.4$$

$$M_x = \frac{Wx^3}{3\ell^2}$$

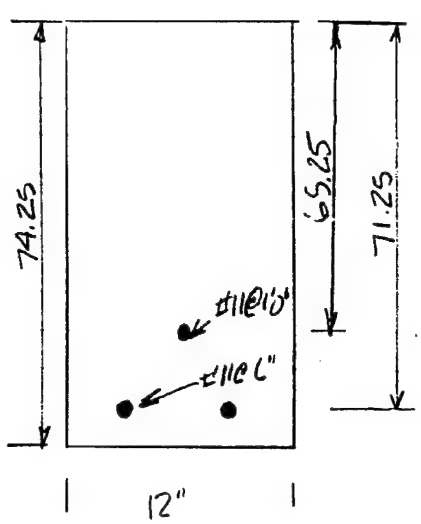
$$M_{@\,33.5} = \frac{(42821.4)(33.5\times12)^3}{3(33.5\times12)^2} = 5{,}738{,}067 \text{ lb·in}$$

5.7×10^6 lb·in

CALCULATE THEORETICAL MOMENT CAPACITY OF THE WALL @ 0.5' INTERVALS

ASSUME DEVELOPMENT OF #11 @ 1'-0" AT BASE 5'5" INTO STEM

#11 @ 1'0" $A_s = 1.56$ in^2
#11 @ 6" $A_s = 3.12$ in^2



$A_s = 3.12 + 1.56 = 4.68$ in^2

$\bar{Y} = d$

A	d	Ad
3.14	71.25	223.73
1.56	65.25	101.75
4.7		325.52

$d = 65.25"$

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SUBJECT HOPKINTON EAST RETAINING WALL
COMPUTATION BACKUP CALCULATIONS
COMPUTED BY M.A.D. CHECKED BY [illegible] DATE 1/14/94

$M_u = \phi M_n$

$= 0.9 A_s f_y (d - a/2)$

$a = \frac{T}{.85 f'_c b} = \frac{A_s f_y}{.85 f'_c b} = \frac{4.68(60)}{.85(3)(12)} = 9.176 \text{ in}$

$M_u = 0.9(4.68)(60)(69.25 - 9.176/2)$

$= (0.9) 18157 \text{ k.in}$

$= 16,341,321 \text{ lb.in}$

$= 16 \times 10^6 \text{ lb.in}$

CALCULATE CRACKING MOMENT.

$M_{CR} = \frac{f_{c_t} I_g}{y_t}$

@ EL 350.5 $f'_c \approx 3000$ psi

$f'_{c_t} = 7.5\sqrt{f'_c} = 411$ psi

$I_g = \frac{bh^3}{12} = \frac{12h^3}{12} = h^3 = (74.25)^3 = 409345$

y_t = DIST FROM CENTROID TO EXTREME TENSION FIBER OF UNCRACKED SECTION.

$= h/2 = 74.25/2 = 37.125$

$M_{CR} = \frac{(411)(409345)}{37.125} = 4,531,738 \text{ lb.in}$

SUBJECT HOPKINTON EAST RETAINING WALL
COMPUTATION BACKUP CALCULATIONS
COMPUTED BY M.A.D. CHECKED BY [illegible] DATE 1/14/94

$M_{(ICE)} + M_{(ACTIVE\ EARTH\ PRESSURE)} > M_{CR}$

- THEN ASSUME SECTION IS CRACKED AT THAT POINT
- IGNORE I_{EFF} DUE TO CANTILEVER BEAM & LIKELIHOOD OF EXTENSIVE CRACKING

IF $M_{ice} + M_{ACT} > M_{CR}$ USE I_{CR} FOR I_{EFF}.

CALCULATE I_{CR}.

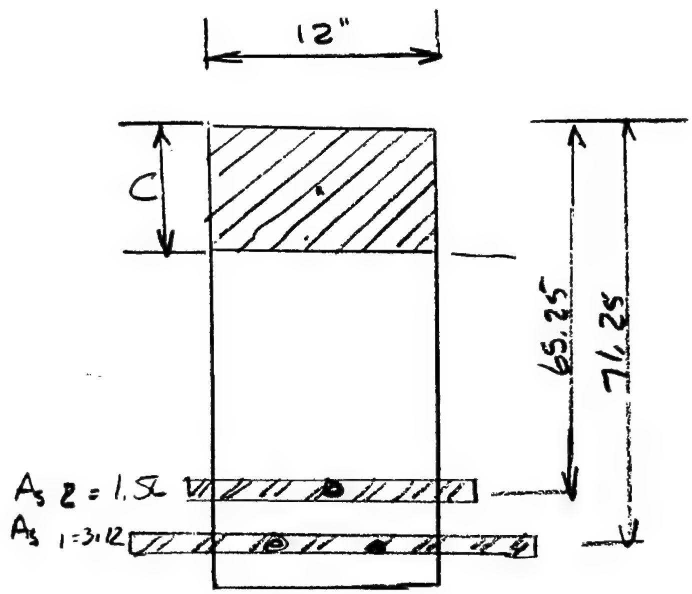
CALCULATE NEUTRAL AXIS.

$E_c = 57000\sqrt{f'c} = 3.12 \times 10^6$

$n = \dfrac{29 \times 10^6}{3.12 \times 10^6} = 9.3$

$A_{s_1}(n) = (3.12)(9.3) = 29.0$

$A_{s_2}(n) \cdot (1.56)(9.3) = 14.5$



LOCATION OF C

ZONE	AREA	$\bar{Y}$	$A\bar{Y}$
COMPRESSION	12c	c/2	$6c^2$
A_{S_1}	29.0	c-71.25	29c - 2066.25
A_{S_2}	14.5	c-65.25	14.5c - 946.13

@ NEUTRAL AXIS $\Sigma A\bar{y} = 0$ $\therefore$ $6c^2 + 43.5c - 3012.38$

$c = \dfrac{-b \pm \sqrt{b^2 - 4AC}}{2A}$ $\dfrac{-43.5 \pm \sqrt{(43.5)^2 - 4(6)(-3012.38)}}{12}$

$c = 19.073$ ←
$c = -26.32$ SINCE C CAN'T BE NEG.

SUBJECT HOPKINTON - EAST RETAINING WALL
COMPUTATION BACK UP CALCULATIONS
COMPUTED BY M.A.D. CHECKED BY DATE 1/14/94

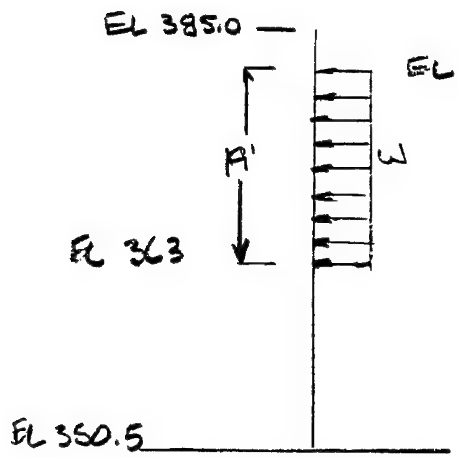
CALCULATE I_{CR} CRACKED MOMENT OF INERTIA.

I

ZONE	AREA	$\bar{y}$	I	Ay^2
COMPRESSION	228.9	9.54	6938.4	20750.6
A_{S_1}	29	-52.18	—	78959.8
A_{S_2}	14.5	-46.18	—	30918.6

$I_{CR} = 137567 \text{ in}^4$

CALCULATE ICE FORCE. - ASSUME UNIFORM DISTRIBUTED LOAD.



MOMENT AT BASE

$$(Wl)\left(363 - 350.5 + \frac{L}{2}\right)$$

USING ICE FORCE OF 620 PLF

$$\left(\frac{620}{12}\right)(19 \times 12)\left(\left(363.0 - 350.5 + \frac{19}{2}\right) \times 12\right)$$

$$(11780)(264)$$

$$= 3109920 \text{ lb}\cdot\text{in}$$

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SUBJECT HOPKINTON - EAST RETAINING WALL

COMPUTATION BACKUP CALCULATIONS

COMPUTED BY M.A.D. CHECKED BY [illegible] DATE 1/14/94

DEFL OF WALL DUE TO ICE LOAD

$$\frac{M_{ICE}}{EI} = \frac{3109920}{(3.12 \times 10^6)(137567)} = 7.24 \times 10^{-6}$$

$$AREA = \left(\left(M/EI_A + M/EI_B\right)/2\right) \times 6''$$

MOMENT ARM = DIST FROM END − 3″

$$\Delta = AREA\ M/EI \times MOMENT\ ARM.$$

REMAINING CALCULATIONS ARE ITERATIVE RECALCULATIONS OF ABOVE CALCULATIONS FOR EACH SECTION AT 6″ SECTIONS

HOPKINTON EAST RETAINING WALL
WALL A - SEC. B-B

Ice Load 615 plf
Ice Deflection 1.19 in
Total Deflection 2.48 in
Overload 0 points exceeding Mu

EL.	HEIGHT FT.	I IN^4	WIDTH in	Icr IN^4	yt	Mcr lb-in	Mact lb-in	Mu lb-in	Mall ice lb-in	Ice force 615	I	EI
350.5	0	409345	74.25	137552	37.13	4531737	5738064	16341321	10603257	3084840	137552	4.3E+11
351.0	0.5	389017	73.00	132155	36.50	4380438	5484952	16025421	10540470	3014730	132155	4.1E+11
351.5	1.0	369773	71.75	126872	35.88	4231707	5239394	15709521	10470127	2944620	126872	4.0E+11
352.0	1.5	350403	70.50	121703	35.25	4085546	5001277	15393621	10392344	2874510	121703	3.8E+11
352.5	2.0	332093	69.25	116648	34.63	3941952	4770486	15077721	10307235	2804400	116648	3.6E+11
353.0	2.5	314432	68.00	111706	34.00	3800928	4546907	14761821	10214914	2734290	111706	3.5E+11
353.5	3.0	297409	66.75	106877	33.38	3662472	4330425	14445921	10115496	2664180	106877	3.3E+11
354.0	3.5	281011	65.50	102161	32.75	3526586	4120925	14130021	10009096	2594070	102161	3.2E+11
354.5	4.0	265228	64.25	97557	32.13	3393267	3918294	13814121	9895827	2523960	97557	3.0E+11
355.0	4.5	250047	63.00	93067	31.50	3262518	3722417	13498221	9775805	2453850	93067	2.9E+11
355.5	5.0	235457	61.75	88688	30.88	3134337	3533178	13182321	9649143	2383740	88688	2.8E+11
356.0	5.5	221445	60.50	84421	30.25	3008726	3350465	12866421	9515956	2313630	84421	2.6E+11
356.5	6.0	208001	59.25	62697	29.63	2885682	3174162	8961649	5787488	2243520	62697	2.0E+11
357.0	6.5	195112	58.00	59693	29.00	2765208	3004155	8751049	5746895	2173410	59693	1.9E+11
357.5	7.0	182767	56.75	56765	28.38	2647302	2840329	8540449	5700121	2103300	56765	1.8E+11
358.0	7.5	170954	55.50	53915	27.75	2531966	2682570	8329849	5647230	2033190	53915	1.7E+11
358.5	8.0	159661	54.25	51142	27.13	2419197	2530763	8119249	5583486	1963080	51142	1.6E+11
359.0	8.5	148877	53.00	48445	26.50	2308998	2384795	7908649	5523855	1892970	48445	1.5E+11
359.5	9.0	138590	51.75	45825	25.88	2201367	2244550	7698049	5453500	1822860	45825	1.4E+11
360.0	9.5	128788	50.50	43282	25.25	2096306	2109914	7487449	5377536	1752750	43282	1.4E+11
360.5	10.0	119459	49.25	34570	24.63	1993812	1980772	6002095	4021322	1682640	34570	1.1E+11
361.0	10.5	110592	48.00	32561	24.00	1893888	1857011	5830645	3973634	1612530	32561	1.0E+11
361.5	11.0	102175	46.75	30616	23.38	1796532	1738515	5659195	3920679	1542420	30616	9.6E+10
362.0	11.5	94196	45.50	28733	22.75	1701746	1625171	5487745	3862574	1472310	28733	9.0E+10
362.5	12.0	86644	44.25	26913	22.13	1609527	1515863	5316295	3799432	1402200	26913	8.4E+10
363.0	12.5	79507	43.00	25155	21.50	1519378	1413477	5144845	3731367	1332090	25155	7.9E+10
363.5	13.0	72773	41.75	23460	20.88	1432797	1314900	4973395	3658495	1262903	23460	7.3E+10
364.0	13.5	66430	40.50	21826	20.25	1348286	1221015	4801945	3580930	1195560	21826	6.8E+10
364.5	14.0	60467	39.25	20255	19.63	1266342	1131709	4630495	3498786	1130063	20255	6.3E+10
365.0	14.5	54872	38.00	18745	19.00	1186968	1046868	4459045	3412177	1066410	18745	5.9E+10
365.5	15.0	49633	36.75	17297	18.38	1110162	966376	4287595	3321219	1004603	17297	5.4E+10
366.0	15.5	44739	35.50	15911	17.75	1035926	890120	4116145	3226025	944640	15911	5.0E+10
366.5	16.0	40177	34.25	14585	17.13	964257	817985	3944695	3126710	886523	14585	4.6E+10
367.0	16.5	35937	33.00	13320	16.50	895158	749856	3773245	3023389	830250	13320	4.2E+10
367.5	17.0	32006	31.75	12116	15.88	828627	685619	3601795	2916176	775823	12116	3.8E+10
368.0	17.5	28373	30.50	10972	15.25	764666	625160	3430345	2905185	723240	10972	3.4E+10
368.5	18.0	25025	29.25	9888	14.63	703272	568363	3258895	2690531	672503	9888	3.1E+10
369.0	18.5	21952	28.00	8864	14.00	644448	515116	3087445	2572329	623610	8864	2.8E+10
369.5	19.0	19141	26.75	7899	13.38	588192	465302	2915995	2450693	576563	7899	2.5E+10
370.0	19.5	16581	25.50	6994	12.75	534506	418808	2744545	2325737	531360	6994	2.2E+10
370.5	20.0	16098	25.25	3263	12.63	524076	375519	1148559	773039	488003	3263	1.0E+10
371.0	20.5	15625	25.00	3184	12.50	513750	335321	1135059	799738	446490	3184	9.9E+09
371.5	21.0	15161	24.75	3106	12.38	503526	298099	1121559	823459	406823	3106	9.7E+09
372.0	21.5	14706	24.50	3029	12.25	493406	263739	1108059	844320	369000	3029	9.5E+09
372.5	22.0	14261	24.25	2953	12.13	483387	232126	1094559	862432	333023	2953	9.2E+09
373.0	22.5	13824	24.00	2878	12.00	473472	203146	1081059	877912	298890	2878	9.0E+09
373.5	23.0	13396	23.75	2804	11.88	463659	176685	1067559	890874	266603	13396	4.2E+10
374.0	23.5	12978	23.50	2731	11.75	453950	152627	1054059	901432	236160	12978	4.1E+10
374.5	24.0	12568	23.25	2659	11.63	444342	130858	1040559	909700	207563	12568	3.9E+10
375.0	24.5	12167	23.00	2588	11.50	434838	111265	1027059	915794	180810	12167	3.8E+10
375.5	25.0	11775	22.75	2519	11.38	425436	93732	1013559	919927	155903	11775	3.7E+10

377.5	27.0	10189	21.75	2249	10.88	388257	41915	959559	917644	74723	10289	3.2E+10
378.0	27.5	9938	21.50	2184	10.75	379970	32967	946059	913091	59040	9938	3.1E+10
378.5	28.0	9596	21.25	2120	10.63	371184	25393	932559	907166	45203	9596	3.0E+10
379.0	28.5	9261	21.00	2057	10.50	362502	19078	919059	899980	33210	9261	2.9E+10
379.5	29.0	8934	20.75	1995	10.38	353922	13908	905559	891651	23063	8934	2.8E+10
380.0	29.5	8615	20.50	1934	10.25	345446	9768	892059	882291	14760	8615	2.7E+10
380.5	30.0	8304	20.25	1874	10.13	337071	6544	878559	872015	8303	8304	2.6E+10
381.0	30.5	8000	20.00	1815	10.00	328800	4121	865059	860938	3690	8000	2.5E+10
381.5	31.0	7704	19.75	1757	9.88	320631	2385	851559	849174	923	7704	2.4E+10
382.0	31.5	7415	19.50	1700	9.75	312566	1221	838059	836838	0	7415	2.3E+10
382.5	32.0	7133	19.25	1645	9.63	304602	515	824559	824044		7133	2.2E+10
383.0	32.5	6859	19.00	1589	9.50	296742	153	811059	810906		6859	2.1E+10
383.5	33.0	6592	18.75	1535	9.38	288984	19	797559	797540		6592	2.1E+10
384.0	33.5	6332	18.50	1482	9.25	281330	0	784059	784059		6332	2.0E+10
384.5	34.0	6078	18.25	1430	9.13	273777		770559	770559		6078	1.9E+10
385.0	34.5	5832	18.00	1379	9.00	266328		757059	757059		5832	1.8E+10

HOPKINTON EAST RETAINING WALL
WALL A - SEC. B-B

		MOMENT									
HEIGHT	I	(LB-IN)	HEIGHT	WIDTH	d	As	fy	a	Mn	Mu
FT	IN^4	ACTIVE	ft	in	in	in	ksi	in	k-in	lb-in
0	409345	5738064.	0	74.250	69.250	4.68	60	9.176	18157.02	16341321
0.5	389017	5484951.	0.5	73.000	68.000	4.68	60	9.176	17806.02	16025421
1.0	369373	5239394.	1.0	71.750	66.750	4.68	60	9.176	17455.02	15709521
1.5	350403	5001277.	1.5	70.500	65.500	4.68	60	9.176	17104.02	15393621
2.0	332093	4770486.	2.0	69.250	64.250	4.68	60	9.176	16753.02	15077721
2.5	314432	4546706.	2.5	68.000	63.000	4.68	60	9.176	16402.02	14761821
3.0	297409	4330424.	3.0	66.750	61.750	4.68	60	9.176	16051.02	14445921
3.5	281011	4120925.	3.5	65.500	60.500	4.68	60	9.176	15700.02	14130021
4.0	265228	3918294.	4.0	64.250	59.250	4.68	60	9.176	15349.02	13814121
4.5	250047	3722416.	4.5	63.000	58.000	4.68	60	9.176	14998.02	13498221
5.0	235457	3533178.	5.0	61.750	56.750	4.68	60	9.176	14647.02	13182321
5.5	221445	3350464.	5.5	60.500	55.500	4.68	60	9.176	14296.02	12866421
6.0	208011	3174161.	6.0	59.250	56.250	3.12	60	6.118	9957.388	8961649
6.5	195112	3004154.	6.5	58.000	55.000	3.12	60	6.118	9723.388	8751049
7.0	182767	2840328.	7.0	56.750	53.750	3.12	60	6.118	9489.388	8540449
7.5	170954	2682569.	7.5	55.500	52.500	3.12	60	6.118	9255.388	8329849
8.0	159661	2530763.	8.0	54.250	51.250	3.12	60	6.118	9021.388	8119249
8.5	148877	2384794.	8.5	53.000	50.000	3.12	60	6.118	8787.388	7908649
9.0	138590	2244549.	9.0	51.750	48.750	3.12	60	6.118	8553.388	7698049
9.5	128788	2109913.	9.5	50.500	47.500	3.12	60	6.118	8319.388	7487449
10.0	119459	1980772.	10.0	49.250	46.250	2.54	60	4.980	6668.994	6002095
10.5	110592	1857011.	10.5	48.000	45.000	2.54	60	4.980	6478.494	5830645
11.0	102175	1738515.	11.0	46.750	43.750	2.54	60	4.980	6287.994	5659195
11.5	94196	1625170.	11.5	45.500	42.500	2.54	60	4.980	6097.494	5487745
12.0	86644	1516863.	12.0	44.250	41.250	2.54	60	4.980	5906.994	5316295
12.5	79507	1413477.	12.5	43.000	40.000	2.54	60	4.980	5716.494	5144845
13.0	72773	1314899.	13.0	41.750	38.750	2.54	60	4.980	5525.994	4973395
13.5	66430	1221014.	13.5	40.500	37.500	2.54	60	4.980	5335.494	4801945
14.0	60467	1131709.	14.0	39.250	36.250	2.54	60	4.980	5144.994	4630495
14.5	54872	1046867.	14.5	38.000	35.000	2.54	60	4.980	4954.494	4459045
15.0	49630	966376.0	15.0	36.750	33.750	2.54	60	4.980	4763.994	4287595
15.5	44739	890119.8	15.5	35.500	32.500	2.54	60	4.980	4573.494	4116145
16.0	40177	817984.6	16.0	34.250	31.250	2.54	60	4.980	4382.994	3944695
16.5	35937	749855.7	16.5	33.000	30.000	2.54	60	4.980	4192.494	3773245
17.0	32006	685618.9	17.0	31.750	28.750	2.54	60	4.980	4001.994	3601795
17.5	28373	625159.6	17.5	30.500	27.500	2.54	60	4.980	3811.494	3430345
18.0	25025	568363.3	18.0	29.250	26.250	2.54	60	4.980	3620.994	3258895
18.5	21952	515115.6	18.5	28.000	25.000	2.54	60	4.980	3430.494	3087445
19.0	19141	465302.0	19.0	26.750	23.750	2.54	60	4.980	3239.994	2915995
19.5	16581	418808.1	19.5	25.500	22.500	2.54	60	4.980	3049.494	2744545
20.0	16098	375519.3	20.0	25.250	22.250	1.00	60	1.961	1276.176	1148559
20.5	15625	335321.2	20.5	25.000	22.000	1.00	60	1.961	1261.176	1135059
21.0	15161	298099.3	21.0	24.750	21.750	1.00	60	1.961	1246.176	1121559
21.5	14706	263739.2	21.5	24.500	21.500	1.00	60	1.961	1231.176	1108059
22.0	14261	232126.3	22.0	24.250	21.250	1.00	60	1.961	1216.176	1094559
22.5	13824	203146.3	22.5	24.000	21.000	1.00	60	1.961	1201.176	1081059
23.0	13396	176684.6	23.0	23.750	20.750	1.00	60	1.961	1186.176	1067559
23.5	12978	152626.8	23.5	23.500	20.500	1.00	60	1.961	1171.176	1054059
24.0	12568	130858.4	24.0	23.250	20.250	1.00	60	1.961	1156.176	1040559
24.5	12167	111264.9	24.5	23.000	20.000	1.00	60	1.961	1141.176	1027059
25.0	11775	93731.97	25.0	22.750	19.750	1.00	60	1.961	1126.176	1013559

[illegible]	[illegible]	[illegible]
27.5	9938	32967.40
28.0	9596	25393.29
28.5	9261	19078.35
29.0	8934	13908.12
29.5	8615	9768.119
30.0	8304	6543.876
30.5	8000	4120.925
31.0	7704	2384.794
31.5	7415	1221.014
32.0	7133	515.1156
32.5	6859	152.6268
33.0	6592	19.07835
33.5	6332	0
34.0	6078	
34.5	5832	

[illegible]	[illegible]	[illegible]	[illegible]	60	[illegible]	[illegible]	[illegible]
27.5	21.500	18.500	1.00	60	1.961	1051.176	946059
28.0	21.250	18.250	1.00	60	1.961	1036.176	932559
28.5	21.000	18.000	1.00	60	1.961	1021.176	919059
29.0	20.750	17.750	1.00	60	1.961	1006.176	905559
29.5	20.500	17.500	1.00	60	1.961	991.1764	892059
30.0	20.250	17.250	1.00	60	1.961	976.1764	878559
30.5	20.000	17.000	1.00	60	1.961	961.1764	865059
31.0	19.750	16.750	1.00	60	1.961	946.1764	851559
31.5	19.500	16.500	1.00	60	1.961	931.1764	838059
32.0	19.250	16.250	1.00	60	1.961	916.1764	824559
32.5	19.000	16.000	1.00	60	1.961	901.1764	811059
33.0	18.750	15.750	1.00	60	1.961	886.1764	797559
33.5	18.500	15.500	1.00	60	1.961	871.1764	784059
34.0	18.250	15.250	1.00	60	1.961	856.1764	770559
34.5	18.000	15.000	1.00	60	1.961	841.1764	757059

IPKINTON EAST RETAINING WALL
ALL A - SEC. B-B

EL.	HEIGHT FT	WIDTH in	d in	Icr IN^4	As	Trans As	c	As2
50.5	0	74.250	71.250	137552	3.12	28.98	19.07	14.49
51.0	0.5	73.000	70.000	132155	3.12	28.98	18.87	14.49
51.5	1.0	71.750	68.750	126872	3.12	28.98	18.67	14.49
52.0	1.5	70.500	67.500	121703	3.12	28.98	18.46	14.49
52.5	2.0	69.250	66.250	116648	3.12	28.98	18.26	14.49
53.0	2.5	68.000	65.000	111706	3.12	28.98	18.05	14.49
53.5	3.0	66.750	63.750	106677	3.12	28.98	17.84	14.49
54.0	3.5	65.500	62.500	102161	3.12	28.98	17.63	14.49
54.5	4.0	64.250	61.250	97557	3.12	28.98	17.41	14.49
55.0	4.5	63.000	60.000	93067	3.12	28.98	17.19	14.49
55.5	5.0	61.750	58.750	88683	3.12	28.98	16.98	14.49
56.0	5.5	60.500	57.500	84421	3.12	28.98	16.75	14.49
56.5	6.0	59.250	56.250	62697	3.12	28.98	14.24	
57.0	6.5	58.000	55.000	59693	3.12	28.98	14.06	
57.5	7.0	56.750	53.750	56765	3.12	28.98	13.88	
58.0	7.5	55.500	52.500	53915	3.12	28.98	13.69	
58.5	8.0	54.250	51.250	51142	3.12	28.98	13.50	
59.0	8.5	53.000	50.000	48445	3.12	28.98	13.31	
59.5	9.0	51.750	48.750	45825	3.12	28.98	13.12	
60.0	9.5	50.500	47.500	43282	3.12	28.98	12.92	
60.5	10.0	49.250	46.250	34570	2.54	23.59	11.66	
61.0	10.5	48.000	45.000	32561	2.54	23.59	11.48	
61.5	11.0	46.750	43.750	30616	2.54	23.59	11.30	
62.0	11.5	45.500	42.500	28733	2.54	23.59	11.11	
62.5	12.0	44.250	41.250	26913	2.54	23.59	10.92	
63.0	12.5	43.000	40.000	25155	2.54	23.59	10.73	
63.5	13.0	41.750	38.750	23460	2.54	23.59	10.53	
64.0	13.5	40.500	37.500	21826	2.54	23.59	10.34	
64.5	14.0	39.250	36.250	20255	2.54	23.59	10.13	
65.0	14.5	38.000	35.000	18745	2.54	23.59	9.93	
65.5	15.0	36.750	33.750	17297	2.54	23.59	9.72	
66.0	15.5	35.500	32.500	15911	2.54	23.59	9.51	
66.5	16.0	34.250	31.250	14585	2.54	23.59	9.29	
67.0	16.5	33.000	30.000	13320	2.54	23.59	9.07	
67.5	17.0	31.750	28.750	12116	2.54	23.59	8.85	
68.0	17.5	30.500	27.500	10972	2.54	23.59	8.62	
68.5	18.0	29.250	26.250	9882	2.54	23.59	8.38	
69.0	18.5	28.000	25.000	8864	2.54	23.59	8.14	
69.5	19.0	26.750	23.750	7899	2.54	23.59	7.90	
70.0	19.5	25.500	22.500	6994	2.54	23.59	7.64	
70.5	20.0	25.250	22.250	3263	1.00	9.29	5.15	
71.0	20.5	25.000	22.000	3184	1.00	9.29	5.11	
71.5	21.0	24.750	21.750	3106	1.00	9.29	5.08	
72.0	21.5	24.500	21.500	3029	1.00	9.29	5.05	
72.5	22.0	24.250	21.250	2953	1.00	9.29	5.01	
73.0	22.5	24.000	21.000	2878	1.00	9.29	4.98	
73.5	23.0	23.750	20.750	2804	1.00	9.29	4.95	
74.0	23.5	23.500	20.500	2731	1.00	9.29	4.91	
74.5	24.0	23.250	20.250	2659	1.00	9.29	4.88	
75.0	24.5	23.000	20.000	2588	1.00	9.29	4.84	

75.5	25.0	22.750	19.750	2518	1.00	9.29	4.81
76.0	25.5	22.500	19.500	2450	1.00	9.29	4.77
76.5	26.0	22.250	19.250	2382	1.00	9.29	4.74
77.0	26.5	22.000	19.000	2315	1.00	9.29	4.70
77.5	27.0	21.750	18.750	2249	1.00	9.29	4.67
78.0	27.5	21.500	18.500	2184	1.00	9.29	4.63
78.5	28.0	21.250	18.250	2120	1.00	9.29	4.60
79.0	28.5	21.000	18.000	2057	1.00	9.29	4.56
79.5	29.0	20.750	17.750	1995	1.00	9.29	4.52
80.0	29.5	20.500	17.500	1934	1.00	9.29	4.49
80.5	30.0	20.250	17.250	1874	1.00	9.29	4.45
81.0	30.5	20.000	17.000	1815	1.00	9.29	4.41
81.5	31.0	19.750	16.750	1757	1.00	9.29	4.38
82.0	31.5	19.500	16.500	1700	1.00	9.29	4.34
82.5	32.0	19.250	16.250	1645	1.00	9.29	4.30
83.0	32.5	19.000	16.000	1589	1.00	9.29	4.26
83.5	33.0	18.750	15.750	1535	1.00	9.29	4.22
84.0	33.5	18.500	15.500	1482	1.00	9.29	4.19
84.5	34.0	18.250	15.250	1430	1.00	9.29	4.15
85.0	34.5	18.000	15.000	1379	1.00	9.29	4.11

NED FORM 223
27 Sept 49

NEW ENGLAND DIVISION

CORPS OF ENGINEERS, U.S. ARMY

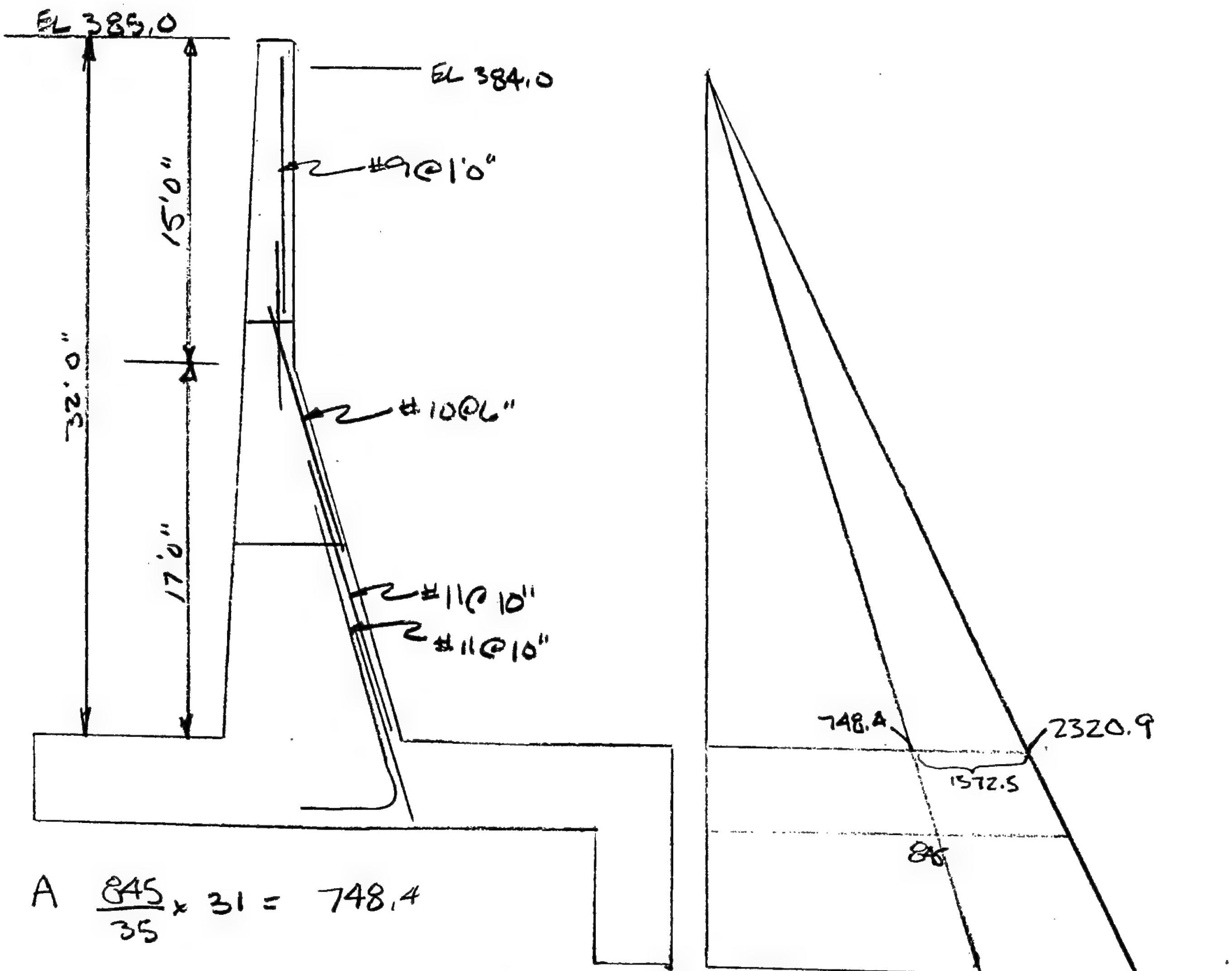
PAGE 7

SUBJECT HOPKINTON EAST WALL B

COMPUTATION BACKUP CALCULATIONS

COMPUTED BY MAD. CHECKED BY JC DATE 1/14/94

WALL B SEC C-C.



A $\frac{845}{35} \times 31 = 748.4$

ACTIVE + POLE PRESSURE - 748.4 + 2320.9 = 2320.9

NED FORM 223
27 Sept 49

NEW ENGLAND DIVISION

CORPS OF ENGINEERS, U.S. ARMY

SUBJECT HOPKINTON EAST WALL B

COMPUTATION BACKUP CALCULATIONS

COMPUTED BY M.A.D. CHECKED BY [illegible] DATE 1/14/94

CALCULATE MOMENT DUE TO ACTIVE PRESSURE + POOL PRESSURE

$$W = \frac{w\ell}{2} = \frac{2320.9(31.)}{2} = 35974.4$$

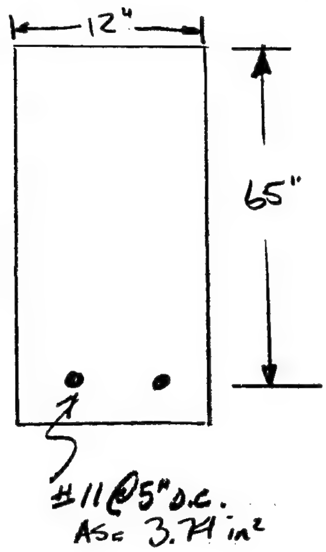
$$M_x = \frac{W x^3}{3\ell^2}$$

@ $x = 31$

$$M @ 31' = \frac{(35974.4)(31 \times 12)^3}{3(31 \times 12)^2} = 4,460,825 \text{ lb.in}$$

CALCULATE THEORETICAL MOMENT CAPACITY OF THE WALL @ .5' INCR

CHECK @ EL 353.0



$$M_U = \phi m_n$$
$$= 0.9 (A_s f_y)(d - a/2)$$

$$A = \frac{A_s f_y}{0.85 f'_c b} = \frac{3.74(60)}{.85(3)(12)} = 7.33$$

$$M_U = 0.9(3.74)(60)\left(65 - \frac{7.33}{2}\right)$$
$$= 12386.88$$
$$= 12,386,880 \text{ lb.in}$$
$$= 12 \times 10^6 \text{ lb.in}$$

SUBJECT HOPKINTON EAST RETAINING WALL B
COMPUTATION BACKUP CALCULATIONS
COMPUTED BY M.A.D CHECKED BY [illegible] DATE 1/19/94

CALCULATE CRACKING MOMENT.

$M_{CR} \; \dfrac{f_{ct} I_g}{y_t}$ @ EL 453.0 $f'_c = 3000$ psi

$f_{ct} \; 7.5\sqrt{f'_c} = 411$ psi

$I_g = \dfrac{bh^3}{12} = \dfrac{12h^3}{12} = h^3 = (68.0)^3 = 314432$

y_t DIST FROM CENTROID TO EXTREME TENSION FIBER OF UNCRACKED SECTION.
$= h/2 = 68/2 = 34$

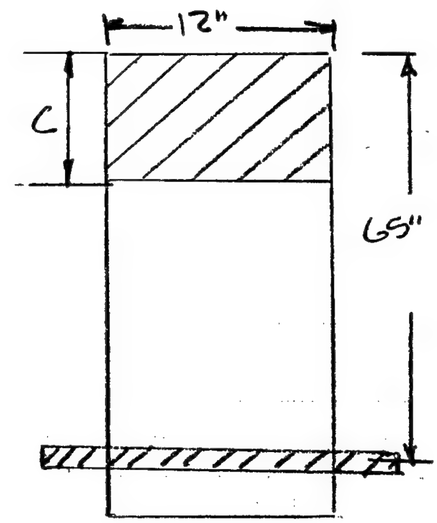
$M_{CR} = \dfrac{411(314432)}{34} = 3.8 \times 10^6$ lb-in

IF $M_{ACTIVE} + M_{ICE} > M_{CR}$

THEN ASSUME FULLY CRACKED SECTION $I = I_{CR}$

CALCULATE I_{CR}

CALCULATE NEUTRAL AXIS



$E_c = 57000\sqrt{f'_c}$
$= 3.12 \times 10^6$

$n = \dfrac{29 \times 10^6}{3.12 \times 10^6} = 9.3$

$A_s = 3.74 \times 9.3 = 34.8$

LOCATION OF C

ZONE	AREA	$\bar{y}$	$A\bar{y}$
COMPRESSION	$12C$	$C/2$	$6C^2$
A_s	34.8	$C-65$	$34.8C - 2260.8$

$\Sigma A\bar{y} = 0 \qquad 6C^2 + 34.8C - 2260.8 = 0$

$C = -34.8 \pm \sqrt{(34.8)^2 - 4(6)(-2260.8)} = 16.72$

SUBJECT HOPKINTON EAST RETAINING WALL B

COMPUTATION BACKUP CALCULATIONS

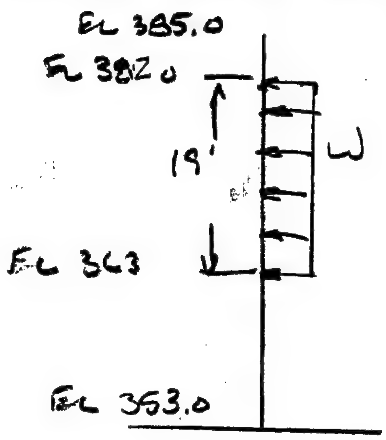
COMPUTED BY M.A.D. CHECKED BY [illegible] DATE 1/19/93

CALCULATE I_{cr} CRACKED MOMENT OF INERTIA @ EL 353.

ZONE	AREA	$\bar{y}$	I	Ay^2
COMPRESSION	200.64	8.36	4674	14022
STEEL	34.8	48.28	—	81117

$I_{cr} = 99813 \text{ in}^4$

CALCULATE ICE FORCE



MOMENT AT BASE

$$wl\left(363 - 353 + 4/2\right)$$

USING ICE FORCE 620 PLF

$$\left(620/12\right)\left(15 \times 12\right)\left(363 - 353 + 19/24\right)(12)$$

2,756,520 lb.in

HOPKINTON EAST RETAINING WALL
WALL B SEC C-C

Ice Load	620 plf	
Ice Deflection	1.10 in	
Total Deflection	2.20 in	
Overload	0 points exceeding Mu	

EL.	HEIGHT FT	I IN^4	WIDTH in	Icr IN^4	yt	Mcr lb-in	Mact lb-in	Mu lb-in	Mall ice lb-in	Ice force 620	I	EI
353.0	0.0	314432	68.00	99675.1	34.00	3800928	4465767	12399335	7933568	2756520	99675	3.1E+11
353.5	0.5	297409	66.75	95528.2	33.38	3662472	4253148	12146615	7893467	2685840	95528	3.0E+11
354.0	1.0	281011	65.50	91473.6	32.75	3526586	4047387	11893895	7846508	2615160	91474	2.9E+11
354.5	1.5	265228	64.25	87511.3	32.13	3393267	3848372	11641175	7792803	2544480	87511	2.7E+11
355.0	2.0	250047	63.00	83641.0	31.50	3262518	3655990	11388455	7732465	2473800	83641	2.6E+11
355.5	2.5	235457	61.75	79862.7	30.88	3134337	3470129	11135735	7665607	2403120	79863	2.5E+11
356.0	3.0	221445	60.50	76176.0	30.25	3008726	3290676	10883015	7592340	2332440	76176	2.4E+11
356.5	3.5	208001	59.25	72580.9	29.63	2885682	3117519	10630295	7512777	2261760	72581	2.3E+11
357.0	4.0	195112	58.00	69077.2	29.00	2765208	2950545	10377575	7427030	2191080	69077	2.2E+11
357.5	4.5	182767	56.75	65664.7	28.38	2647302	2789643	10124855	7335212	2120400	65665	2.1E+11
358.0	5.0	170954	55.50	62343.1	27.75	2531966	2634699	9872135.	7237436	2049720	62343	1.9E+11
358.5	5.5	159661	54.25	59112.3	27.13	2419197	2485602	9619415.	7133814	1979040	59112	1.8E+11
359.0	6.0	148877	53.00	55972.1	26.50	2308998	2342238	9366695.	7024457	1908360	55972	1.7E+11
359.5	6.5	138590	51.75	52922.3	25.88	2201367	2204496	9113975.	6909480	1837680	52922	1.7E+11
360.0	7.0	128788	50.50	49962.6	25.25	2096306	2072262	8861255.	6788993	1767000	49963	1.6E+11
360.5	7.5	119459	49.25	34570.0	24.63	1993812	1945425	6002094.	4056669	1696320	34570	1.1E+11
361.0	8.0	110592	48.00	32561.4	24.00	1893888	1823873	5830644.	4006772	1625640	32561	1.0E+11
361.5	8.5	102175	46.75	30615.8	23.38	1796532	1707491	5659194.	3951703	1554960	30616	9.6E+10
362.0	9.0	94196	45.50	28732.9	22.75	1701746	1596170	5487744.	3891575	1484280	28733	9.0E+10
362.5	9.5	86644	44.25	26912.7	22.13	1609527	1489794	5316294.	3826500	1413600	26913	8.4E+10
363.0	10.0	79507	43.00	25155.0	21.50	1519878	1388254	5144844.	3756591	1342920	25155	7.9E+10
363.5	10.5	72773	41.75	23459.5	20.88	1432797	1291435	4973394.	3681960	1273170	23460	7.3E+10
364.0	11.0	66430	40.50	21826.2	20.25	1348286	1199226	4801944.	3602719	1205280	21826	6.8E+10
364.5	11.5	60467	39.25	20254.9	19.63	1266342	1111514	4630494.	3518981	1139250	20255	6.3E+10
365.0	12.0	54872	38.00	18745.3	19.00	1186968	1028186	4459044.	3430858	1075080	18745	5.9E+10
365.5	12.5	49633	36.75	17297.2	18.38	1110162	949131	4287594.	3338464	1012770	17297	5.4E+10
366.0	13.0	44739	35.50	15910.5	17.75	1035926	874236	4116144.	3241909	952320	15911	5.0E+10
366.5	13.5	40177	34.25	14584.9	17.13	964257	803388	3944694.	3141307	893730	14585	4.6E+10
367.0	14.0	35937	33.00	13320.1	16.50	895158	736475	3773244.	3036770	837000	13320	4.2E+10
367.5	14.5	32006	31.75	12115.9	15.88	828627	673384	3601794.	2928411	782130	12116	3.8E+10
368.0	15.0	28373	30.50	10972.0	15.25	764666	614004	3430344.	2816341	729120	10972	3.4E+10
368.5	15.5	25025	29.25	9888.26	14.63	703272	558221	3258894.	2700674	677970	9888	3.1E+10
369.0	16.0	21952	28.00	8864.15	14.00	644448	505923	3087444.	2581521	628680	8864	2.8E+10
369.5	16.5	19141	26.75	7899.42	13.38	588192	456999	2915994.	2458996	581250	7899	2.5E+10
370.0	17.0	16581	25.50	6993.72	12.75	534506	411334	2744544.	2333210	535680	6994	2.2E+10
370.5	17.5	16098	25.25	3262.51	12.63	524076	368818	1148558.	779741	491970	3263	1.0E+10
371.0	18.0	15625	25.00	3183.58	12.50	513750	329337	1135058.	805721	450120	3184	9.9E+09
371.5	18.5	15161	24.75	3105.65	12.38	503526	292780	1121558.	828779	410130	3106	9.7E+09
372.0	19.0	14706	24.50	3028.73	12.25	493406	259033	1108058.	849026	372000	3029	9.5E+09
372.5	19.5	14261	24.25	2952.82	12.13	483387	227984	1094558.	866575	335730	2953	9.2E+09
373.0	20.0	13824	24.00	2877.92	12.00	473472	199521	1081058.	881538	301320	2878	9.0E+09
373.5	20.5	13396	23.75	2804.02	11.88	463659	173532	1067558.	894027	268770	13396	4.2E+10
374.0	21.0	12978	23.50	2731.12	11.75	453950	149903	1054058.	904156	238080	12978	4.1E+10
374.5	21.5	12568	23.25	2659.22	11.63	444342	128523	1040558.	912036	209250	12568	3.9E+10
375.0	22.0	12167	23.00	2588.33	11.50	434838	109279	1027058.	917779	182280	12167	3.8E+10
375.5	22.5	11775	22.75	2518.44	11.38	425436	92059	1013558.	921500	157170	11775	3.7E+10
376.0	23.0	11391	22.50	2449.55	11.25	416138	76750	1000058.	923308	133920	11391	3.6E+10
376.5	23.5	11015	22.25	2381.66	11.13	406941	63240	986558.8	923318	112530	11015	3.4E+10
377.0	24.0	10648	22.00	2314.77	11.00	397848	51417	973058.8	921642	93000	10648	3.3E+10
377.5	24.5	10289	21.75	2248.87	10.88	388857	41167	959558.8	918392	75330	10289	3.2E+10
378.0	25.0	[illegible]	21.50	[illegible]	10.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

379.5	26.5	8934	20.75	1975.23	10.38	353922	13660	905558.8	891899	23230	8934	2.8E+10
380.0	27.0	8615	20.50	1934.50	10.25	345446	9594	892058.8	882465	14880	8615	2.7E+10
380.5	27.5	8304	20.25	1874.37	10.13	337071	6427	878558.8	872132	8370	8304	2.6E+10
381.0	28.0	8000	20.00	1815.42	10.00	328800	4047	865058.8	861011	3720	8000	2.5E+10
381.5	28.5	7704	19.75	1757.46	9.88	320631	2342	851558.8	849217	930	7704	2.4E+10
382.0	29.0	7415	19.50	1700.48	9.75	312566	1199	838058.8	836860	0	7415	2.3E+10
382.5	29.5	7133	19.25	1644.50	9.63	304602	506	824558.8	824053		7133	2.2E+10
383.0	30.0	6859	19.00	1589.49	9.50	296742	150	811058.8	810909		6859	2.1E+10
383.5	30.5	6592	18.75	1535.47	9.38	288984	19	797558.8	797540		6592	2.1E+10
384.0	31.0	6332	18.50	1482.43	9.25	281330	0	784058.8	784059		6332	2.0E+10
384.5	31.5	6078	18.25	1430.37	9.13	273777		770558.8	770559		6078	1.9E+10
385.0	32.0	5832	18.00	1379.29	9.00	266328		757058.8	757059		5832	1.8E+10

HOPKINTON EAST RETAINING WALL
WALL B SEC. C-C

EL.	HEIGHT FT	Ig IN^4	MOMENT (LB-IN) ACTIVE	HEIGHT ft	WIDTH in	d in	As in	fy ksi	a in	Mn k-in	oMn lb-in
353.0	0.0	314432	4465767	0.0	68.000	65.000	3.74	60	7.341	13777	12399335
353.5	0.5	297409	4253148	0.5	66.750	63.750	3.74	60	7.341	13496	12146615
354.0	1.0	281011	4047387	1.0	65.500	62.500	3.74	60	7.341	13215	11893895
354.5	1.5	265228	3848372	1.5	64.250	61.250	3.74	60	7.341	12935	11641175
355.0	2.0	250047	3655990	2.0	63.000	60.000	3.74	60	7.341	12654	11388455
355.5	2.5	235457	3470129	2.5	61.750	58.750	3.74	60	7.341	12373	11135735
356.0	3.0	221445	3290676	3.0	60.500	57.500	3.74	60	7.341	12092	10883015
356.5	3.5	208001	3117519	3.5	59.250	56.250	3.74	60	7.341	11811	10630295
357.0	4.0	195112	2950545	4.0	58.000	55.000	3.74	60	7.341	11531	10377575
357.5	4.5	182767	2789643	4.5	56.750	53.750	3.74	60	7.341	11250	10124855
358.0	5.0	170954	2634699	5.0	55.500	52.500	3.74	60	7.341	10969	9872135
358.5	5.5	159661	2485602	5.5	54.250	51.250	3.74	60	7.341	10688	9619415
359.0	6.0	148877	2342238	6.0	53.000	50.000	3.74	60	7.341	10407	9366695
359.5	6.5	138590	2204496	6.5	51.750	48.750	3.74	60	7.341	10127	9113975
360.0	7.0	128788	2072262	7.0	50.500	47.500	3.74	60	7.341	9846	8861255
360.5	7.5	119459	1945425	7.5	49.250	46.250	2.54	60	4.980	6669	6002095
361.0	8.0	110592	1823873	8.0	48.000	45.000	2.54	60	4.980	6478	5830645
361.5	8.5	102175	1707491	8.5	46.750	43.750	2.54	60	4.980	6288	5659195
362.0	9.0	94196	1596170	9.0	45.500	42.500	2.54	60	4.980	6097	5487745
362.5	9.5	86644	1489794	9.5	44.250	41.250	2.54	60	4.980	5907	5316295
363.0	10.0	79507	1388254	10.0	43.000	40.000	2.54	60	4.980	5716	5144845
363.5	10.5	72773	1291435	10.5	41.750	38.750	2.54	60	4.980	5526	4973395
364.0	11.0	66430	1199226	11.0	40.500	37.500	2.54	60	4.980	5335	4801945
364.5	11.5	60467	1111514	11.5	39.250	36.250	2.54	60	4.980	5145	4630495
365.0	12.0	54872	1028186	12.0	38.000	35.000	2.54	60	4.980	4954	4459045
365.5	12.5	49633	949131	12.5	36.750	33.750	2.54	60	4.980	4764	4287595
366.0	13.0	44739	874236	13.0	35.500	32.500	2.54	60	4.980	4573	4116145
366.5	13.5	40177	803388	13.5	34.250	31.250	2.54	60	4.980	4383	3944695
367.0	14.0	35937	736475	14.0	33.000	30.000	2.54	60	4.980	4192	3773245
367.5	14.5	32006	673384	14.5	31.750	28.750	2.54	60	4.980	4002	3601795
368.0	15.0	28373	614004	15.0	30.500	27.500	2.54	60	4.980	3811	3430345
368.5	15.5	25025	558221	15.5	29.250	26.250	2.54	60	4.980	3621	3258895
369.0	16.0	21952	505923	16.0	28.000	25.000	2.54	60	4.980	3430	3087445
369.5	16.5	19141	456999	16.5	26.750	23.750	2.54	60	4.980	3240	2915995
370.0	17.0	16581	411334	17.0	25.500	22.500	2.54	60	4.980	3049	2744545
370.5	17.5	16098	368818	17.5	25.250	22.250	1.00	60	1.961	1276	1148559
371.0	18.0	15625	329337	18.0	25.000	22.000	1.00	60	1.961	1261	1135059
371.5	18.5	15161	292780	18.5	24.750	21.750	1.00	60	1.961	1246	1121559
372.0	19.0	14706	259033	19.0	24.500	21.500	1.00	60	1.961	1231	1108059
372.5	19.5	14261	227984	19.5	24.250	21.250	1.00	60	1.961	1216	1094559
373.0	20.0	13824	199521	20.0	24.000	21.000	1.00	60	1.961	1201	1081059
373.5	20.5	13396	173532	20.5	23.750	20.750	1.00	60	1.961	1186	1067559
374.0	21.0	12978	149903	21.0	23.500	20.500	1.00	60	1.961	1171	1054059
374.5	21.5	12568	128523	21.5	23.250	20.250	1.00	60	1.961	1156	1040559
375.0	22.0	12167	109279	22.0	23.000	20.000	1.00	60	1.961	1141	1027059
375.5	22.5	11775	92059	22.5	22.750	19.750	1.00	60	1.961	1126	1013559
376.0	23.0	11391	76750	23.0	22.500	19.500	1.00	60	1.961	1111	1000059
376.5	23.5	11015	63240	23.5	22.250	19.250	1.00	60	1.961	1096	986559
377.0	24.0	10648	51417	24.0	22.000	19.000	1.00	60	1.961	1081	973059
377.5	24.5	10289	41167	24.5	21.750	18.750	1.00	60	1.961	1066	959559
378.0	25.0	9938	32379	25.0	21.500	18.500	1.00	60	1.961	1051	946059
378.5	25.5	9596	24940	25.5	21.250	18.250	1.00	60	1.961	1036	932559
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

380.5	27.5	8304	6427	27.5	20.250	17.250	1.00	60	1.961	976	878559
381.0	28.0	8000	4047	28.0	20.000	17.000	1.00	60	1.961	961	865059
381.5	28.5	7704	2342	28.5	19.750	16.750	1.00	60	1.961	946	851559
382.0	29.0	7415	1199	29.0	19.500	16.500	1.00	60	1.961	931	838059
382.5	29.5	7133	506	29.5	19.250	16.250	1.00	60	1.961	916	824559
383.0	30.0	6859	150	30.0	19.000	16.000	1.00	60	1.961	901	811059
383.5	30.5	6592	19	30.5	18.750	15.750	1.00	60	1.961	886	797559
384.0	31.0	6332	0	31.0	18.500	15.500	1.00	60	1.961	871	784059
384.5	31.5	6078	-19	31.5	18.250	15.250	1.00	60	1.961	856	770559
385.0	32.0	5832	-150	32.0	18.000	15.000	1.00	60	1.961	841	757059

KINTON EAST RETAINING WALL
L B - SEC. C-C

EL.	HEIGHT FT	WIDTH in	d in	Icr IN^4	As	Trans Ay	c
353.0	0.0	68.000	65.000	99675.16	3.74	34.74034	16.72
353.5	0.5	66.750	63.750	95528.21	3.74	34.74034	16.53
354.0	1.0	65.500	62.500	91473.65	3.74	34.74034	16.35
354.5	1.5	64.250	61.250	87511.32	3.74	34.74034	16.16
355.0	2.0	63.000	60.000	83641.06	3.74	34.74034	15.97
355.5	2.5	61.750	58.750	79862.70	3.74	34.74034	15.77
356.0	3.0	60.500	57.500	76176.06	3.74	34.74034	15.58
356.5	3.5	59.250	56.250	72580.98	3.74	34.74034	15.38
357.0	4.0	58.000	55.000	69077.26	3.74	34.74034	15.18
357.5	4.5	56.750	53.750	65664.73	3.74	34.74034	14.98
358.0	5.0	55.500	52.500	62343.17	3.74	34.74034	14.78
358.5	5.5	54.250	51.250	59112.39	3.74	34.74034	14.57
359.0	6.0	53.000	50.000	55972.19	3.74	34.74034	14.36
359.5	6.5	51.750	48.750	52922.34	3.74	34.74034	14.15
360.0	7.0	50.500	47.500	49962.61	3.74	34.74034	13.94
360.5	7.5	49.250	46.250	34570.08	2.54	23.59370	11.66
361.0	8.0	48.000	45.000	32561.48	2.54	23.59370	11.48
361.5	8.5	46.750	43.750	30615.82	2.54	23.59370	11.30
362.0	9.0	45.500	42.500	28732.96	2.54	23.59370	11.11
362.5	9.5	44.250	41.250	26912.74	2.54	23.59370	10.92
363.0	10.0	43.000	40.000	25155.01	2.54	23.59370	10.73
363.5	10.5	41.750	38.750	23459.58	2.54	23.59370	10.53
364.0	11.0	40.500	37.500	21826.29	2.54	23.59370	10.34
364.5	11.5	39.250	36.250	20254.94	2.54	23.59370	10.13
365.0	12.0	38.000	35.000	18745.34	2.54	23.59370	9.93
365.5	12.5	36.750	33.750	17297.29	2.54	23.59370	9.72
366.0	13.0	35.500	32.500	15910.56	2.54	23.59370	9.51
366.5	13.5	34.250	31.250	14584.92	2.54	23.59370	9.29
367.0	14.0	33.000	30.000	13320.14	2.54	23.59370	9.07
367.5	14.5	31.750	28.750	12115.96	2.54	23.59370	8.85
368.0	15.0	30.500	27.500	10972.09	2.54	23.59370	8.62
368.5	15.5	29.250	26.250	9888.263	2.54	23.59370	8.38
369.0	16.0	28.000	25.000	8864.150	2.54	23.59370	8.14
369.5	16.5	26.750	23.750	7899.424	2.54	23.59370	7.90
370.0	17.0	25.500	22.500	6993.727	2.54	23.59370	7.64
370.5	17.5	25.250	22.250	3262.518	1.00	9.288862	5.15
371.0	18.0	25.000	22.000	3183.583	1.00	9.288862	5.11
371.5	18.5	24.750	21.750	3105.657	1.00	9.288862	5.08
372.0	19.0	24.500	21.500	3028.739	1.00	9.288862	5.05
372.5	19.5	24.250	21.250	2952.827	1.00	9.288862	5.01
373.0	20.0	24.000	21.000	2877.921	1.00	9.288862	4.98
373.5	20.5	23.750	20.750	2804.020	1.00	9.288862	4.95
374.0	21.0	23.500	20.500	2731.122	1.00	9.288862	4.91
374.5	21.5	23.250	20.250	2659.228	1.00	9.288862	4.88
375.0	22.0	23.000	20.000	2588.336	1.00	9.288862	4.84
375.5	22.5	22.750	19.750	2518.445	1.00	9.288862	4.81
376.0	23.0	22.500	19.500	2449.555	1.00	9.288862	4.77
376.5	23.5	22.250	19.250	2381.663	1.00	9.288862	4.74
377.0	24.0	22.000	19.000	2314.770	1.00	9.288862	4.70
377.5	24.5	21.750	18.750	2248.873	1.00	9.288862	4.67

378.0	25.0	21.500	18.500	2183.973	1.00	9.288862	4.63
378.5	25.5	21.250	18.250	2120.067	1.00	9.288862	4.60
379.0	26.0	21.000	18.000	2057.155	1.00	9.288862	4.56
379.5	26.5	20.750	17.750	1995.236	1.00	9.288862	4.52
380.0	27.0	20.500	17.500	1934.308	1.00	9.288862	4.49
380.5	27.5	20.250	17.250	1874.371	1.00	9.288862	4.45
381.0	28.0	20.000	17.000	1815.423	1.00	9.288862	4.41
381.5	28.5	19.750	16.750	1757.462	1.00	9.288862	4.38
382.0	29.0	19.500	16.500	1700.489	1.00	9.288862	4.34
382.5	29.5	19.250	16.250	1644.500	1.00	9.288862	4.30
383.0	30.0	19.000	16.000	1589.496	1.00	9.288862	4.26
383.5	30.5	18.750	15.750	1535.474	1.00	9.288862	4.22
384.0	31.0	18.500	15.500	1482.433	1.00	9.288862	4.19
384.5	31.5	18.250	15.250	1430.373	1.00	9.288862	4.15
385.0	32.0	18.000	15.000	1379.291	1.00	9.288862	4.11

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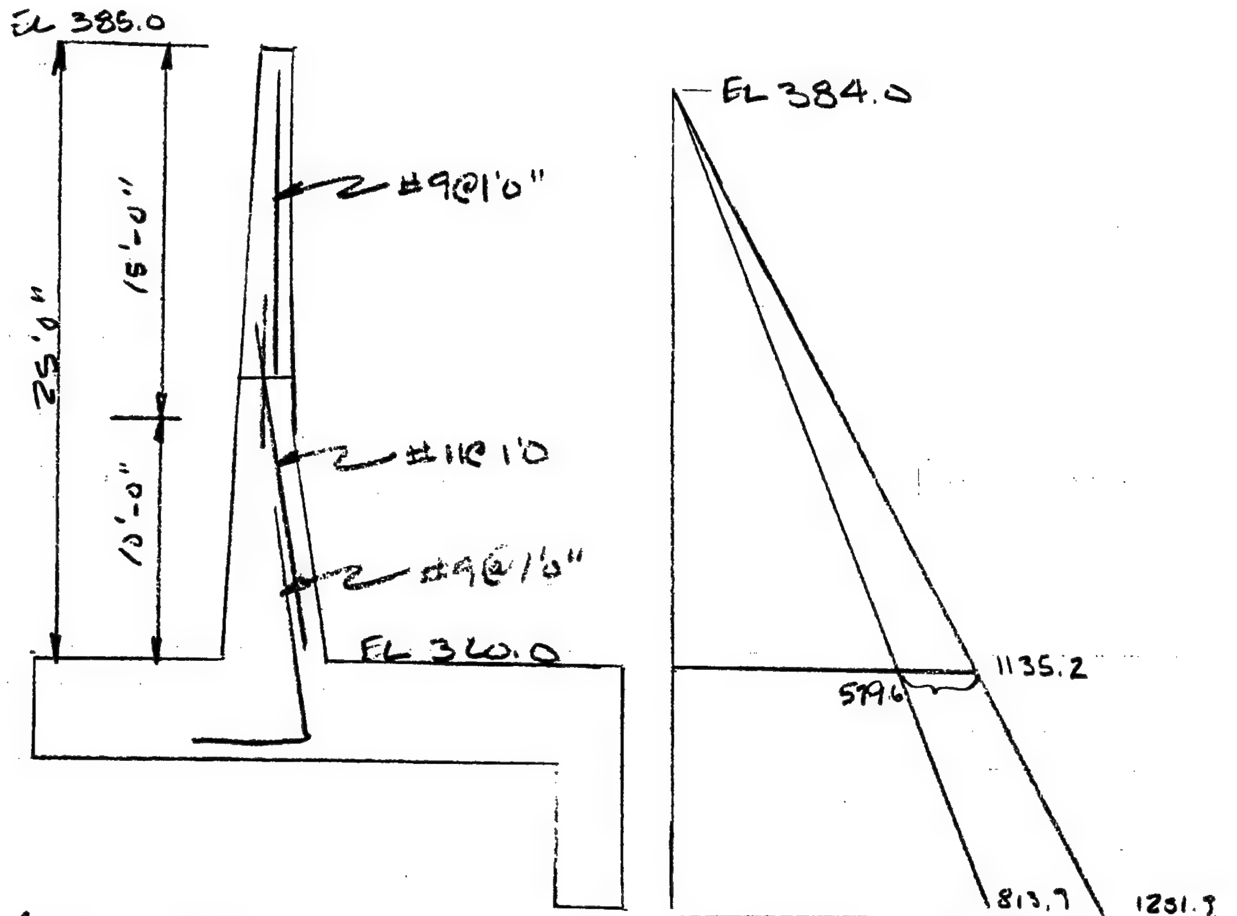
SUBJECT HOPKINTON EAST WALL C

COMPUTATION BACK UP CALCULATIONS

COMPUTED BY M.D. CHECKED BY ______ DATE 1/19/94



ACTIVE + PORE PRESSURE = 1135.2 + 579.6 ACTIVE PORE PRESS
= 1714.8 lb/ft²

CALCULATE MOMENT DUE TO ACTIVE + PORE PRESSURES

$$W = \frac{wl}{2} = (1714.8)\frac{24}{2} = 20577.6 \text{ lb}$$

$$M = \frac{wx^3}{3l^2} \qquad M@25' = \frac{20577.6(24\times12)^3}{3(24\times12)^2} = 1975449 \text{ lb.in}$$

NED FORM 223
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SUBJECT HOPKINTON EAST WALL C

COMPUTATION BACKUP CALCULATIONS

COMPUTED BY M.D. CHECKED BY ______ DATE 1/19/94

CALCULATE THEORETICAL MOMENT CAPACITY AT EL 360.0
d, 5' INCR.

$$M_U = \phi M_n = 0.9(A_s f_y)(d - a/2) \qquad a = \frac{A_s f_y}{.85 f'_c b} = \frac{1.0(60)}{.85(3)(12)}$$

$$= 1.96$$

$$M_U = 0.9(1)(60)(47.5 - 1.96/2)$$

$$= 2512080 \text{ in.lb}$$

$$= 2.5 \times 10^6 \text{ in.lb} \longleftarrow \text{LOW}$$

CALCULATE CRACKING MOMENT

$$M_{cr} = \frac{f'_{ct} I_g}{y_t} \qquad f_{ct} = 7.5\sqrt{f'c} = 411$$

$$I_g = (50.5)^3 = 128787. \text{ in}^4$$

CALCULATE I_{CR}

LOCATION OF C

ZONE	AREA	$\bar{Y}$	$A\bar{Y}$
COMPRESSION	12C	C/2	$6C^2$
A.S	9.3	C-47.5	9.3C - 441.8

$$\Sigma A_y = 0 \qquad 6C^2 + 9.3C - 441.8 = 0$$

$$C = \frac{-9.3 \pm \sqrt{(9.3)^2 - 4(6)(441.8)}}{12} = 7.84$$

NED FORM 223
27 Sept 49

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U.S. ARMY

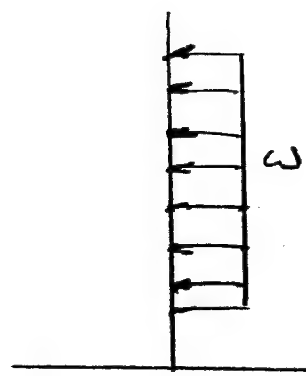
SUBJECT HOPKINTON EAST WALL C
COMPUTATION BACKUP CALCULATIONS
COMPUTED BY M.A.D CHECKED BY DATE 1/19/94

I_{CR}

ZONE	AREA	$\bar{y}$	I	Ay^2
COMPRESSION	94.08	3.92	481.9	1445.7
STEEL	9.3	39.66	—	14628

$I_{CR} = 16556 \text{ in}^4$

CALCULATE ICE FORCE



$w\ell \,(363 - 360 + 4/2)$

using ice = 200 plf

$\left(\frac{200}{12}\right)(19 \times 12)\left(363 - 360 + 19/2\right)12$

$= 570{,}000 \text{ in}\cdot\text{lb}$

HOPKINTON EAST RETAINING WALL
WALL C. - SEC. D-D

Ice Load 200 plf
Ice Deflection 0.45 in
Total Deflection 1.70 in
Overload 1 points exceeding Mu

EL.	HEIGHT FT	I IN^4	WIDTH in	Icr IN^4	yt	Mcr lb-in	Mact lb-in	Mu lb-in	Mall ice lb-in	Ice force 200	I	EI
360.0	0.0	128788	50.50	16538.1	25.25	2096306	1975450	2512058.	536609	570000	16538	5.2E+10
360.5	0.5	119459	49.25	15630.2	24.63	1993812	1854538	2444558.	590020	547200	15630	4.9E+10
361.0	1.0	110592	48.00	14748.7	24.00	1893888	1738664	2377058.	638395	524400	14749	4.6E+10
361.5	1.5	102175	46.75	13893.6	23.38	1796532	1627720	2309558.	681839	501600	13894	4.3E+10
362.0	2.0	94196	45.50	13064.8	22.75	1701746	1521599	2242058.	720460	478800	13065	4.1E+10
362.5	2.5	86644	44.25	12262.2	22.13	1609527	1420194	2174558.	754365	456000	12262	3.8E+10
363.0	3.0	79507	43.00	11485.8	21.50	1519878	1323397	2107058.	783662	433200	11486	3.6E+10
363.5	3.5	72773	41.75	15716.1	20.88	1432797	1231101	3135462.	1904361	410700	15716	4.9E+10
364.0	4.0	66430	40.50	14641.5	20.25	1348286	1143200	3030162.	1886962	388800	14642	4.6E+10
364.5	4.5	60467	39.25	13606.6	19.63	1266342	1059586	2924862.	1865277	367500	13607	4.2E+10
365.0	5.0	54872	38.00	12611.1	19.00	1186968	980151	2819562.	1839411	346800	12611	3.9E+10
365.5	5.5	49633	36.75	11655.1	18.38	1110162	904789	2714262.	1809473	326700	11655	3.6E+10
366.0	6.0	44739	35.50	10738.3	17.75	1035926	833393	2608962.	1775570	307200	10738	3.4E+10
366.5	6.5	40177	34.25	9860.69	17.13	964257	765855	2503662.	1737808	288300	9861	3.1E+10
367.0	7.0	35937	33.00	9022.11	16.50	895158	702068	2398362.	1696295	270000	9022	2.8E+10
367.5	7.5	32006	31.75	8222.45	15.88	828627	641925	2293062.	1651138	252300	8222	2.6E+10
368.0	8.0	28373	30.50	7461.59	15.25	764666	585318	2187762.	1602444	235200	7462	2.3E+10
368.5	8.5	25025	29.25	6739.36	14.63	703272	532142	2082462.	1550321	218700	6739	2.1E+10
369.0	9.0	21952	28.00	6055.63	14.00	644448	482287	1977162.	1494875	202800	6056	1.9E+10
369.5	9.5	19141	26.75	5410.23	13.38	588192	435649	1871862.	1436214	187500	5410	1.7E+10
370.0	10.0	16581	25.50	4802.97	12.75	534506	392118	1766562.	1374445	172800	4803	1.5E+10
370.5	10.5	16098	25.25	3262.51	12.63	524076	351588	1148558.	796971	158700	16098	5.0E+10
371.0	11.0	15625	25.00	3183.58	12.50	513750	313951	1135058.	821108	145200	15625	4.9E+10
371.5	11.5	15161	24.75	3105.65	12.38	503526	279102	1121558.	842457	132300	15161	4.7E+10
372.0	12.0	14706	24.50	3028.73	12.25	493406	246931	1108058.	861128	120000	14706	4.6E+10
372.5	12.5	14261	24.25	2952.82	12.13	483387	217333	1094558.	877226	108300	14261	4.5E+10
373.0	13.0	13824	24.00	2877.92	12.00	473472	190200	1081058.	890859	97200	13824	4.3E+10
373.5	13.5	13396	23.75	2804.02	11.88	463659	165425	1067558.	902134	86700	13396	4.2E+10
374.0	14.0	12978	23.50	2731.12	11.75	453950	142900	1054058.	911159	76800	12978	4.1E+10
374.5	14.5	12568	23.25	2659.22	11.63	444342	122519	1040558.	918040	67500	12568	3.9E+10
375.0	15.0	12167	23.00	2588.33	11.50	434838	104174	1027058.	922885	58800	12167	3.8E+10
375.5	15.5	11775	22.75	2518.44	11.38	425436	87758	1013558.	925800	50700	11775	3.7E+10
376.0	16.0	11391	22.50	2449.55	11.25	416138	73165	1000058.	926894	43200	11391	3.6E+10
376.5	16.5	11015	22.25	2381.66	11.13	406941	60286	986558.8	926273	36300	11015	3.4E+10
377.0	17.0	10648	22.00	2314.77	11.00	397848	49015	973058.8	924044	30000	10648	3.3E+10
377.5	17.5	10289	21.75	2248.87	10.88	388857	39244	959558.8	920315	24300	10289	3.2E+10
378.0	18.0	9938	21.50	2183.97	10.75	379970	30866	946058.8	915192	19200	9938	3.1E+10
378.5	18.5	9596	21.25	2120.06	10.63	371184	23775	932558.8	908784	14700	9596	3.0E+10
379.0	19.0	9261	21.00	2057.15	10.50	362502	17863	919058.8	901196	10800	9261	2.9E+10
379.5	19.5	8934	20.75	1995.23	10.38	353922	13022	905558.8	892537	7500	8934	2.8E+10
380.0	20.0	8615	20.50	1934.30	10.25	345446	9146	892058.8	882913	4800	8615	2.7E+10
380.5	20.5	8304	20.25	1874.37	10.13	337071	6127	878558.8	872432	2700	8304	2.6E+10
381.0	21.0	8000	20.00	1815.42	10.00	328800	3858	865058.8	861201	1200	8000	2.5E+10
381.5	21.5	7704	19.75	1757.46	9.88	320631	2233	851558.8	849326	300	7704	2.4E+10
382.0	22.0	7415	19.50	1700.48	9.75	312566	1143	838058.8	836916	0	7415	2.3E+10
382.5	22.5	7133	19.25	1644.50	9.63	304602	482	824558.8	824077		7133	2.2E+10
383.0	23.0	6859	19.00	1589.49	9.50	296742	143	811058.8	810916		6859	2.1E+10
383.5	23.5	6592	18.75	1535.47	9.38	288984	18	797558.8	797541		6592	2.1E+10
384.0	24.0	6332	18.50	1482.43	9.25	281330	0	784058.8	784059		6332	2.0E+10
384.5	24.5	6078	18.25	1430.37	9.13	273777	-18	770558.8	770577		6078	1.9E+10
385.0	25.0	[illegible]	18.00	[illegible]	9.00	[illegible]	-147	[illegible]	[illegible]		[illegible]	[illegible]

HOPKINTON EAST RETAINING WALL
WALL C. - SEC.D-D

	HEIGHT FT	Ic IN^4	MOMENT (LB-IN) ACTIVE	HEIGHT ft	WIDTH in	d in	As in	fy ksi	a in	Mn k-in	φMn lb-in
360.0	0.0	128788	1975450	0.0	50.500	47.500	1.00	60	1.961	2791.176	2512058.
360.5	0.5	119459	1854538	0.5	49.250	46.250	1.00	60	1.961	2716.176	2444558.
361.0	1.0	110592	1738664	1.0	48.000	45.000	1.00	60	1.961	2641.176	2377058.
361.5	1.5	102175	1627720	1.5	46.750	43.750	1.00	60	1.961	2566.176	2309558.
362.0	2.0	94196	1521599	2.0	45.500	42.500	1.00	60	1.961	2491.176	2242058.
362.5	2.5	86644	1420194	2.5	44.250	41.250	1.00	60	1.961	2416.176	2174558.
363.0	3.0	79507	1323397	3.0	43.000	40.000	1.00	60	1.961	2341.176	2107058.
363.5	3.5	72773	1231101	3.5	41.750	38.750	1.56	60	3.059	3483.847	3135462.
364.0	4.0	66430	1143200	4.0	40.500	37.500	1.56	60	3.059	3366.847	3030162.
364.5	4.5	60467	1059586	4.5	39.250	36.250	1.56	60	3.059	3249.847	2924862.
365.0	5.0	54872	980151	5.0	38.000	35.000	1.56	60	3.059	3132.847	2819562.
365.5	5.5	49633	904789	5.5	36.750	33.750	1.56	60	3.059	3015.847	2714262.
366.0	6.0	44739	833393	6.0	35.500	32.500	1.56	60	3.059	2898.847	2608962.
366.5	6.5	40177	765855	6.5	34.250	31.250	1.56	60	3.059	2781.847	2503662.
367.0	7.0	35937	702068	7.0	33.000	30.000	1.56	60	3.059	2664.847	2398362.
367.5	7.5	32006	641925	7.5	31.750	28.750	1.56	60	3.059	2547.847	2293062.
368.0	8.0	28373	585318	8.0	30.500	27.500	1.56	60	3.059	2430.847	2187762.
368.5	8.5	25025	532142	8.5	29.250	26.250	1.56	60	3.059	2313.847	2082462.
369.0	9.0	21952	482287	9.0	28.000	25.000	1.56	60	3.059	2196.847	1977162.
369.5	9.5	19141	435649	9.5	26.750	23.750	1.56	60	3.059	2079.847	1871862.
370.0	10.0	16581	392118	10.0	25.500	22.500	1.56	60	3.059	1962.847	1766562.
370.5	10.5	16098	351588	10.5	25.250	22.250	1.00	60	1.961	1276.176	1148558.
371.0	11.0	15625	313951	11.0	25.000	22.000	1.00	60	1.961	1261.176	1135058.
371.5	11.5	15161	279102	11.5	24.750	21.750	1.00	60	1.961	1246.176	1121558.
372.0	12.0	14706	246931	12.0	24.500	21.500	1.00	60	1.961	1231.176	1108058.
372.5	12.5	14261	217333	12.5	24.250	21.250	1.00	60	1.961	1216.176	1094558.
373.0	13.0	13824	190200	13.0	24.000	21.000	1.00	60	1.961	1201.176	1081058.
373.5	13.5	13396	165425	13.5	23.750	20.750	1.00	60	1.961	1186.176	1067558.
374.0	14.0	12978	142900	14.0	23.500	20.500	1.00	60	1.961	1171.176	1054058.
374.5	14.5	12568	122519	14.5	23.250	20.250	1.00	60	1.961	1156.176	1040558.
375.0	15.0	12167	104174	15.0	23.000	20.000	1.00	60	1.961	1141.176	1027058.
375.5	15.5	11775	87758	15.5	22.750	19.750	1.00	60	1.961	1126.176	1013558.
376.0	16.0	11391	73165	16.0	22.500	19.500	1.00	60	1.961	1111.176	1000058.
376.5	16.5	11015	60286	16.5	22.250	19.250	1.00	60	1.961	1096.176	986558.8
377.0	17.0	10648	49015	17.0	22.000	19.000	1.00	60	1.961	1081.176	973058.8
377.5	17.5	10289	39244	17.5	21.750	18.750	1.00	60	1.961	1066.176	959558.8
378.0	18.0	9938	30866	18.0	21.500	18.500	1.00	60	1.961	1051.176	946058.8
378.5	18.5	9596	23775	18.5	21.250	18.250	1.00	60	1.961	1036.176	932558.8
379.0	19.0	9261	17863	19.0	21.000	18.000	1.00	60	1.961	1021.176	919058.8
379.5	19.5	8934	13022	19.5	20.750	17.750	1.00	60	1.961	1006.176	905558.8
380.0	20.0	8615	9146	20.0	20.500	17.500	1.00	60	1.961	991.1764	892058.8
380.5	20.5	8304	6127	20.5	20.250	17.250	1.00	60	1.961	976.1764	878558.8
381.0	21.0	8000	3858	21.0	20.000	17.000	1.00	60	1.961	961.1764	865058.8
381.5	21.5	7704	2233	21.5	19.750	16.750	1.00	60	1.961	946.1764	851558.8
382.0	22.0	7415	1143	22.0	19.500	16.500	1.00	60	1.961	931.1764	838058.8
382.5	22.5	7133	482	22.5	19.250	16.250	1.00	60	1.961	916.1764	824558.8
383.0	23.0	6859	143	23.0	19.000	16.000	1.00	60	1.961	901.1764	811058.8
383.5	23.5	6592	18	23.5	18.750	15.750	1.00	60	1.961	886.1764	797558.8
384.0	24.0	6332	0	24.0	18.500	15.500	1.00	60	1.961	871.1764	784058.8
384.5	24.5	6078	-18	24.5	18.250	15.250	1.00	60	1.961	856.1764	770558.8
385.0	25.0	5832	-143	25.0	18.000	15.000	1.00	60	1.961	841.1764	757058.8

HOPKINTON EAST RETAINING WALL
WALL C. - SEC. D-D

EL.	HEIGHT FT	WIDTH in	d in	Icr IN^4	As	Trans Ay	c
360.0	0.0	50.500	47.500	16538.15	1.00	9.288862	7.84
360.5	0.5	49.250	46.250	15630.27	1.00	9.288862	7.72
361.0	1.0	48.000	45.000	14748.78	1.00	9.288862	7.61
361.5	1.5	46.750	43.750	13893.63	1.00	9.288862	7.49
362.0	2.0	45.500	42.500	13064.80	1.00	9.288862	7.37
362.5	2.5	44.250	41.250	12262.23	1.00	9.288862	7.25
363.0	3.0	43.000	40.000	11485.89	1.00	9.288862	7.13
363.5	3.5	41.750	38.750	15716.12	1.56	14.49062	8.54
364.0	4.0	40.500	37.500	14641.59	1.56	14.49062	8.39
364.5	4.5	39.250	36.250	13606.65	1.56	14.49062	8.23
365.0	5.0	38.000	35.000	12611.19	1.56	14.49062	8.07
365.5	5.5	36.750	33.750	11655.11	1.56	14.49062	7.90
366.0	6.0	35.500	32.500	10738.32	1.56	14.49062	7.73
366.5	6.5	34.250	31.250	9860.695	1.56	14.49062	7.56
367.0	7.0	33.000	30.000	9022.116	1.56	14.49062	7.39
367.5	7.5	31.750	28.750	8222.459	1.56	14.49062	7.21
368.0	8.0	30.500	27.500	7461.590	1.56	14.49062	7.03
368.5	8.5	29.250	26.250	6739.366	1.56	14.49062	6.85
369.0	9.0	28.000	25.000	6055.634	1.56	14.49062	6.66
369.5	9.5	26.750	23.750	5410.231	1.56	14.49062	6.46
370.0	10.0	25.500	22.500	4802.979	1.56	14.49062	6.26
370.5	10.5	25.250	22.250	3262.518	1.00	9.288862	5.15
371.0	11.0	25.000	22.000	3183.583	1.00	9.288862	5.11
371.5	11.5	24.750	21.750	3105.657	1.00	9.288862	5.08
372.0	12.0	24.500	21.500	3028.739	1.00	9.288862	5.05
372.5	12.5	24.250	21.250	2952.827	1.00	9.288862	5.01
373.0	13.0	24.000	21.000	2877.921	1.00	9.288862	4.98
373.5	13.5	23.750	20.750	2804.020	1.00	9.288862	4.95
374.0	14.0	23.500	20.500	2731.122	1.00	9.288862	4.91
374.5	14.5	23.250	20.250	2659.228	1.00	9.288862	4.88
375.0	15.0	23.000	20.000	2588.336	1.00	9.288862	4.84
375.5	15.5	22.750	19.750	2518.445	1.00	9.288862	4.81
376.0	16.0	22.500	19.500	2449.555	1.00	9.288862	4.77
376.5	16.5	22.250	19.250	2381.663	1.00	9.288862	4.74
377.0	17.0	22.000	19.000	2314.770	1.00	9.288862	4.70
377.5	17.5	21.750	18.750	2248.873	1.00	9.288862	4.67
378.0	18.0	21.500	18.500	2183.973	1.00	9.288862	4.63
378.5	18.5	21.250	18.250	2120.067	1.00	9.288862	4.60
379.0	19.0	21.000	18.000	2057.155	1.00	9.288862	4.56
379.5	19.5	20.750	17.750	1995.236	1.00	9.288862	4.52
380.0	20.0	20.500	17.500	1934.308	1.00	9.288862	4.49
380.5	20.5	20.250	17.250	1874.371	1.00	9.288862	4.45
381.0	21.0	20.000	17.000	1815.423	1.00	9.288862	4.41
381.5	21.5	19.750	16.750	1757.462	1.00	9.288862	4.38
382.0	22.0	19.500	16.500	1700.489	1.00	9.288862	4.34
382.5	22.5	19.250	16.250	1644.500	1.00	9.288862	4.30
383.0	23.0	19.000	16.000	1589.496	1.00	9.288862	4.26
383.5	23.5	18.750	15.750	1535.474	1.00	9.288862	4.22
384.0	24.0	18.500	15.500	1482.433	1.00	9.288862	4.19
384.5	24.5	18.250	15.250	1430.373	1.00	9.288862	4.15
385.0	25.0	18.000	15.000	1379.291	1.00	9.288862	4.11

NED FORM 223
27 Sept 49

NEW ENGLAND DIVISION

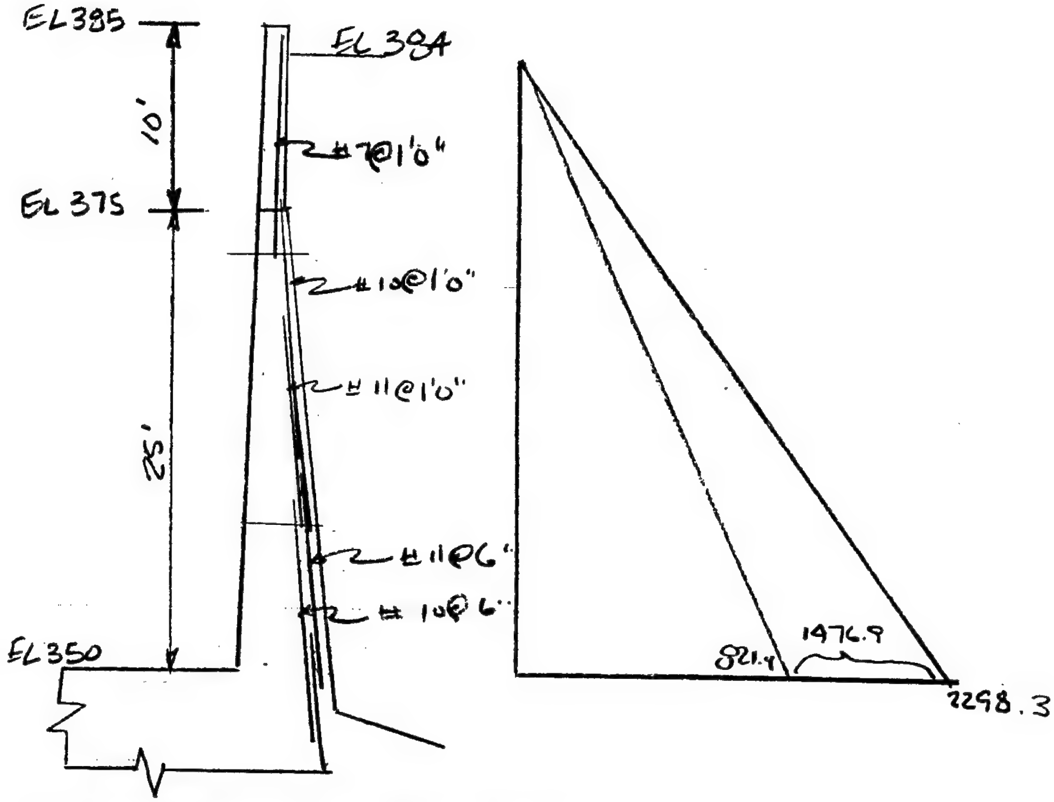
CORPS OF ENGINEERS, U.S. ARMY

SUBJECT HOPKINTON EAST RETAINING WALL

COMPUTATION BACKUP CALCULATIONS STILLING BASIN WALL

COMPUTED BY M.A.D. CHECKED BY [illegible] DATE 1/21/94

WALL - STILLING BASIN.



ACTIVE PRESSURE + POLE PRESSURE

$$W = \frac{wl}{2} = \frac{2298.3(34)}{2} = 39071.1$$

$$M_x = \frac{Wx^2}{3l^2} \quad M@34 \quad \frac{(39071.1)(34\times12)^3}{3(34\times12)^2} = 5313669.$$

NED FORM 223
27 Sept 49

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U.S. ARMY

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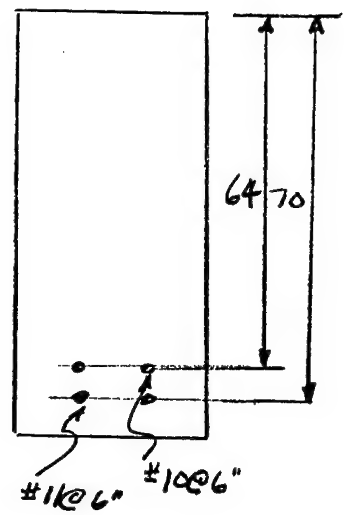
SUBJECT HOPKINTON EAST RETAINING WALL
COMPUTATION BACKUP CALCULATIONS STILLING BASIN WALL
COMPUTED BY MAD CHECKED BY DATE 1/21/94

CALCULATE THEORETICAL MOMENT CAPACITY



	d_i	Ad	
A_{s_1}	3.12	70	218.4
A_{s_2}	2.54	64	162.6
	5.66		381.0

$d = 67.307$

$$M_U = \phi m_n = 0.9 A_s f_y (d - a/2) \qquad a = \frac{A_s f_y}{(.85 f'_c b)} = \frac{5.66(60)}{.85(3)(12)}$$

$$\phi m_n = 0.9(5.66)(60)(67.307 - 11.09/2) \qquad = 11.098$$

$$M_U = 18875715 \text{ lb.in}$$

$$= 18.8 \times 10^6 \text{ lb-in}$$

CALCULATE CRACKING MOMENT M_{CR}

$$M_{CR} \quad \frac{f_{r} I_g}{y_t} \qquad f_r = 7.5\sqrt{f'_c} = 7.5\sqrt{3000} = 411$$

$$I_g = \frac{12(73)^3}{12} = 389017 \text{ in}^4$$

$$y_t = 73/2 = 36.5$$

$$M_{cr} = \frac{(411)(389017)}{36.5} = 4380438 \text{ lb.in}$$

NED FORM 223
27 Sept 49

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U.S. ARMY

SUBJECT HOPKINTON EAST RETAINING WALL

COMPUTATION BACKUP CALCULATING STILLING BASIN

COMPUTED BY M.A.D CHECKED BY DATE 1/21/94

CALCULATE I_{cr}

$E_c = 57000\sqrt{f'c} = 3.12\times10^6$

$n = 9.28$

A_{s1} $3.12 \times 9.28 = 28.91$
A_{s2} $2.54 \times 9.29 = 23.59$

LOCATION OF C

ZONE	AREA	$\bar{Y}$	$A\bar{Y}$
COMPRESSION	12c	c/2	$6c^2$
A_{s1}	28.91	c-70	28.91c - 2023.7
A_{s2}	23.59	c-64	23.59c - 1509.76

$6c^2 - 52.5 - 3533.46$

$c = \dfrac{-b \pm \sqrt{b^2 - 4AC}}{2A}$ $\quad \dfrac{-52.5 \pm \sqrt{(52.5)^2 + 4(6)(3533.46)}}{12}$

$c = 20.3$

CALCULATE I_{cr}

ZONE	AREA	$\bar{Y}$	I	$A\bar{Y}$
COMPRESSION	243.4	10.15	8365	25075.7
A_{s1}	28.9	49.7	—	71385.6
A_{s2}	23.6	43.7	—	45068.7
				149895

$I_{cr} = 149895\ in^4$

CALCULATE ICE FORCE

MOMENT AT BASE $W\ell(363 - 350 + 4/2)$

USING ICE FORCE 620 lb

$(620)(19)(363 - 350 + 5/2)(12) = 3180600$ lb-in

HOPKINTON EAST RETAINING WALL
STILLING BASIN WALL

Ice Load	620 plf
Ice Deflection	0.81 in
Total Deflection	1.65 in
Overload	0 points exceeding Mu

EL. N.G.V.	HEIGHT FT	I IN^4	WIDTH in	Icr IN^4	yt in	Mcr lb-in	Mact lb-in	Mu lb-in	Mall ice lb-in	Ice force 620	I	EI
350.0	0	389017	73.00	150105	36.50	4380438	5313670	18875838	13562168	3180600	150105	4.7E+11
350.5	0.5	373248	72.00	145205	36.00	4261248	5082674	18570198	13487524	3109920	145205	4.5E+11
351.0	1.0	357911	71.00	140391	35.50	4143702	4858471	18264558	13406087	3039240	140391	4.4E+11
351.5	1.5	343000	70.00	135664	35.00	4027800	4640961	17958918	13317957	2968560	135664	4.2E+11
352.0	2.0	328509	69.00	131022	34.50	3913542	4430041	17653278	13223237	2897880	131022	4.1E+11
352.5	2.5	314432	68.00	126467	34.00	3800928	4225610	17347638	13122027	2827200	126467	3.9E+11
353.0	3.0	300763	67.00	121997	33.50	3689958	4027568	17041998	13014430	2756520	121997	3.8E+11
353.5	3.5	287496	66.00	117613	33.00	3580632	3835812	16736358	12900546	2685840	117613	3.7E+11
354.0	4.0	274625	65.00	113314	32.50	3472950	3650241	16430718	12780476	2615160	113314	3.5E+11
354.5	4.5	262144	64.00	109101	32.00	3366912	3470754	16125078	12654324	2544480	109101	3.4E+11
355.0	5.0	250047	63.00	104973	31.50	3262518	3297249	15819438	12522188	2473800	104973	3.3E+11
355.5	5.5	238328	62.00	100930	31.00	3159768	3129626	15513798	12384172	2403120	100930	3.2E+11
356.0	6.0	226981	61.00	96971	30.50	3058662	2967781	15208158	12240376	2332440	96971	3.0E+11
356.5	6.5	216000	60.00	67199	30.00	2959200	2811615	14902518	12090902	2261760	67199	2.1E+11
357.0	7.0	205379	59.00	64649	29.50	2861382	2661026	14596878	11935852	2191080	64649	2.0E+11
357.5	7.5	195112	58.00	62150	29.00	2765208	2515912	14291238	11775326	2120400	62150	1.9E+11
358.0	8.0	185193	57.00	59702	28.50	2670678	2376172	13985598	11609426	2049720	59702	1.9E+11
358.5	8.5	175616	56.00	57305	28.00	2577792	2241704	13679958	11438253	1979040	57305	1.8E+11
359.0	9.0	166375	55.00	54959	27.50	2486550	2112408	13374318	11261910	1908360	54959	1.7E+11
359.5	9.5	157464	54.00	52664	27.00	2396952	1988182	13068678	11080496	1837680	52664	1.6E+11
360.0	10.0	148877	53.00	50420	26.50	2308998	1868923	12763038	10894114	1767000	50420	1.6E+11
360.5	10.5	140608	52.00	48227	26.00	2222688	1754532	12457398	10702865	1696320	48227	1.5E+11
361.0	11.0	132651	51.00	46085	25.50	2138022	1644907	12151758	10506851	1625640	46085	1.4E+11
361.5	11.5	125000	50.00	43993	25.00	2055000	1539945	11846118	10306172	1554960	43993	1.4E+11
362.0	12.0	117649	49.00	41952	24.50	1973622	1439547	11540478	10100931	1484280	41952	1.3E+11
362.5	12.5	110592	48.00	35539	24.00	1893888	1343610	6452899	5109290	1413600	35539	1.1E+11
363.0	13.0	103823	47.00	33827	23.50	1815798	1252033	6300079	5048047	1342920	33827	1.1E+11
363.5	13.5	97336	46.00	32160	23.00	1739352	1164714	6147259	4982545	1273170	32160	1.0E+11
364.0	14.0	91125	45.00	30537	22.50	1664550	1081553	5994439	4912886	1205280	30537	9.5E+10
364.5	14.5	85184	44.00	28958	22.00	1591392	1002447	5841619	4839172	1139250	28958	9.0E+10
365.0	15.0	79507	43.00	27423	21.50	1519878	927296	5688799	4761503	1075080	27423	8.6E+10
365.5	15.5	74088	42.00	25933	21.00	1450008	855998	5535979	4679981	1012770	25933	8.1E+10
366.0	16.0	68921	41.00	24486	20.50	1381782	788452	5383159	4594707	952320	24486	7.6E+10
366.5	16.5	64000	40.00	23083	20.00	1315200	724556	5230339	4505783	893730	23083	7.2E+10
367.0	17.0	59319	39.00	21723	19.50	1250262	664209	5077519	4413311	837000	21723	6.8E+10
367.5	17.5	54872	38.00	20408	19.00	1186968	607309	4924699	4317391	782130	20408	6.4E+10
368.0	18.0	50653	37.00	19135	18.50	1125318	553755	4771879	4218124	729120	19135	6.0E+10
368.5	18.5	46656	36.00	9345	18.00	1065312	503446	2177751	1674305	677970	9345	2.9E+10
369.0	19.0	42875	35.00	8745	17.50	1006950	456280	2109171	1652891	628680	8745	2.7E+10
369.5	19.5	39304	34.00	8166	17.00	950232	412156	2040591	1628435	581250	8166	2.5E+10
370.0	20.0	35937	33.00	7607	16.50	895158	370973	1972011	1601039	535680	7607	2.4E+10
370.5	20.5	32768	32.00	7069	16.00	841728	332628	1903431	1570803	491970	32768	1.0E+11
371.0	21.0	29791	31.00	6552	15.50	789942	297021	1834851	1537830	450120	29791	9.3E+10
371.5	21.5	27000	30.00	6055	15.00	739800	264051	1766271	1502220	410130	27000	8.4E+10
372.0	22.0	24389	29.00	5578	14.50	691302	233615	1697691	1464076	372000	24389	7.6E+10
372.5	22.5	21952	28.00	2706	14.00	644448	205613	790941	585328	335730	21952	6.9E+10
373.0	23.0	19683	27.00	2481	13.50	599238	179943	758541	578598	301320	19683	6.1E+10
373.5	23.5	17576	26.00	2266	13.00	555672	156504	726141	569637	268770	17576	5.5E+10
374.0	24.0	15625	25.00	2061	12.50	513750	135194	693741	558547	238080	15625	4.9E+10
374.5	24.5	13824	24.00	1867	12.00	473472	115912	661341	545429	209250	13824	4.3E+10
375.0	25.0	12167	23.00	1682	11.50	434938	98557	628941	530385	182280	12167	3.8E+10
375.5	25.5	11775	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11775	[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
377.0	27.0	10648	22.00	1507	11.00	397848	46372	596541	550170	93000	10648	3.3E+10
377.5	27.5	10289	21.75	1465	10.88	388657	37128	588441	551313	75330	10289	3.2E+10
378.0	28.0	9938	21.50	1423	10.75	379970	29202	580341	551139	59520	9938	3.1E+10
378.5	28.5	9596	21.25	1382	10.63	371184	22493	572241	549748	45570	9596	3.0E+10
379.0	29.0	9261	21.00	1342	10.50	362502	16899	564141	547242	33480	9261	2.9E+10
379.5	29.5	8934	20.75	1303	10.38	353922	12320	556041	543722	23250	8934	2.8E+10
380.0	30.0	8615	20.50	1263	10.25	345446	8652	547941	539289	14880	8615	2.7E+10
380.5	30.5	8304	20.25	1225	10.13	337071	5796	539841	534045	8370	8304	2.6E+10
381.0	31.0	8000	20.00	1187	10.00	328800	3650	531741	528091	3720	8000	2.5E+10
381.5	31.5	7704	19.75	1150	9.88	320631	2112	523641	521529	930	7704	2.4E+10
382.0	32.0	7415	19.50	1113	9.75	312566	1082	515541	514460	0	7415	2.3E+10
382.5	32.5	7133	19.25	1077	9.63	304602	456	507441	506985		7133	2.2E+10
383.0	33.0	6859	19.00	1042	9.50	296742	135	499341	499206		6859	2.1E+10
383.5	33.5	6592	18.75	1007	9.38	288984	17	491241	491224		6592	2.1E+10
384.0	34.0	6332	18.50	973	9.25	281330	0	483141	483141		6332	2.0E+10
384.5	34.5	6078	18.25	940	9.13	273777		475041	475041		6078	1.9E+10
385.0	35.0	5832	18.00	907	9.00	266328		466941	466941		5832	1.8E+10

HOPKINTON EAST RETAINING WALL
STILLING BASIN WALL

EL. N.G.V.D	HEIGHT FT	Ig IN^4	MOMENT (LB-IN) ACTIVE	HEIGHT ft	WIDTH in	d in	As in	fy ksi	a in	Mn k-in	Mu lb-in
350.0	0	389017	5313670	0	73.000	67.307	5.66	60	11.098	20973.15	18875838
350.5	0.5	373248	5082674	0.5	72.000	66.307	5.66	60	11.098	20633.55	18570198
351.0	1.0	357911	4858471	1.0	71.000	65.307	5.66	60	11.098	20293.95	18264558
351.5	1.5	343000	4640961	1.5	70.000	64.307	5.66	60	11.098	19954.35	17958918
352.0	2.0	328509	4430041	2.0	69.000	63.307	5.66	60	11.098	19614.75	17653278
352.5	2.5	314432	4225610	2.5	68.000	62.307	5.66	60	11.098	19275.15	17347638
353.0	3.0	300763	4027568	3.0	67.000	61.307	5.66	60	11.098	18935.55	17041998
353.5	3.5	287496	3835812	3.5	66.000	60.307	5.66	60	11.098	18595.95	16736358
354.0	4.0	274625	3650241	4.0	65.000	59.307	5.66	60	11.098	18256.35	16430718
354.5	4.5	262144	3470754	4.5	64.000	58.307	5.66	60	11.098	17916.75	16125078
355.0	5.0	250047	3297249	5.0	63.000	57.307	5.66	60	11.098	17577.15	15819438
355.5	5.5	238328	3129626	5.5	62.000	56.307	5.66	60	11.098	17237.55	15513798
356.0	6.0	226981	2967781	6.0	61.000	55.307	5.66	60	11.098	16897.95	15208158
356.5	6.5	216000	2811615	6.5	60.000	54.307	5.66	60	11.098	16558.35	14902518
357.0	7.0	205379	2661026	7.0	59.000	53.307	5.66	60	11.098	16218.75	14596878
357.5	7.5	195112	2515912	7.5	58.000	52.307	5.66	60	11.098	15879.15	14291238
358.0	8.0	185193	2376172	8.0	57.000	51.307	5.66	60	11.098	15539.55	13985598
358.5	8.5	175616	2241704	8.5	56.000	50.307	5.66	60	11.098	15199.95	13679958
359.0	9.0	166375	2112408	9.0	55.000	49.307	5.66	60	11.098	14860.35	13374318
359.5	9.5	157464	1988182	9.5	54.000	48.307	5.66	60	11.098	14520.75	13068678
360.0	10.0	148877	1868923	10.0	53.000	47.307	5.66	60	11.098	14181.15	12763038
360.5	10.5	140608	1754532	10.5	52.000	46.307	5.66	60	11.098	13841.55	12457398
361.0	11.0	132651	1644907	11.0	51.000	45.307	5.66	60	11.098	13501.95	12151758
361.5	11.5	125000	1539945	11.5	50.000	44.307	5.66	60	11.098	13162.35	11846118
362.0	12.0	117649	1439547	12.0	49.000	43.307	5.66	60	11.098	12822.75	11540478
362.5	12.5	110592	1343610	12.5	48.000	45.000	2.83	60	5.549	7169.888	6452899
363.0	13.0	103823	1252033	13.0	47.000	44.000	2.83	60	5.549	7000.088	6300079
363.5	13.5	97336	1164714	13.5	46.000	43.000	2.83	60	5.549	6830.288	6147259
364.0	14.0	91125	1081553	14.0	45.000	42.000	2.83	60	5.549	6660.488	5994439
364.5	14.5	85184	1002447	14.5	44.000	41.000	2.83	60	5.549	6490.688	5841619
365.0	15.0	79507	927296	15.0	43.000	40.000	2.83	60	5.549	6320.888	5688799
365.5	15.5	74088	855998	15.5	42.000	39.000	2.83	60	5.549	6151.088	5535979
366.0	16.0	68921	788452	16.0	41.000	38.000	2.83	60	5.549	5981.288	5383159
366.5	16.5	64000	724556	16.5	40.000	37.000	2.83	60	5.549	5811.488	5230339
367.0	17.0	59319	664209	17.0	39.000	36.000	2.83	60	5.549	5641.688	5077519
367.5	17.5	54872	607309	17.5	38.000	35.000	2.83	60	5.549	5471.888	4924699
368.0	18.0	50653	553755	18.0	37.000	34.000	2.83	60	5.549	5302.088	4771879
368.5	18.5	46656	503446	18.5	36.000	33.000	1.27	60	2.490	2419.723	2177751
369.0	19.0	42875	456280	19.0	35.000	32.000	1.27	60	2.490	2343.523	2109171
369.5	19.5	39304	412156	19.5	34.000	31.000	1.27	60	2.490	2267.323	2040591
370.0	20.0	35937	370973	20.0	33.000	30.000	1.27	60	2.490	2191.123	1972011
370.5	20.5	32768	332628	20.5	32.000	29.000	1.27	60	2.490	2114.923	1903431
371.0	21.0	29791	297021	21.0	31.000	28.000	1.27	60	2.490	2038.723	1834851
371.5	21.5	27000	264051	21.5	30.000	27.000	1.27	60	2.490	1962.523	1766271
372.0	22.0	24389	233615	22.0	29.000	26.000	1.27	60	2.490	1886.323	1697691
372.5	22.5	21952	205613	22.5	28.000	25.000	0.60	60	1.176	878.8235	790941
373.0	23.0	19683	179943	23.0	27.000	24.000	0.60	60	1.176	842.8235	758541
373.5	23.5	17576	156504	23.5	26.000	23.000	0.60	60	1.176	806.8235	726141
374.0	24.0	15625	135194	24.0	25.000	22.000	0.60	60	1.176	770.8235	693741
374.5	24.5	13824	115912	24.5	24.000	21.000	0.60	60	1.176	734.8235	661341
375.0	25.0	12167	98557	25.0	23.000	20.000	0.60	60	1.176	698.8235	628941
375.5	25.5	11775	83026	25.5	22.750	19.750	0.60	60	1.176	689.8235	620841
376.0	26.0	11391	69219	26.0	22.500	19.500	0.60	60	1.176	680.8235	612741
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

378.0	28.0	9935	29202	28.0	21.500	18.500	0.60	60	1.176	644.8235	580341
378.5	28.5	9596	22493	28.5	21.250	18.250	0.60	60	1.176	635.8235	572241
379.0	29.0	9261	16899	29.0	21.000	18.000	0.60	60	1.176	626.8235	564141
379.5	29.5	8934	12320	29.5	20.750	17.750	0.60	60	1.176	617.8235	556041
380.0	30.0	8615	8652	30.0	20.500	17.500	0.60	60	1.176	608.8235	547941
380.5	30.5	8304	5796	30.5	20.250	17.250	0.60	60	1.176	599.8235	539641
381.0	31.0	8000	3650	31.0	20.000	17.000	0.60	60	1.176	590.8235	531741
381.5	31.5	7704	2112	31.5	19.750	16.750	0.60	60	1.176	581.8235	523641
382.0	32.0	7415	1082	32.0	19.500	16.500	0.60	60	1.176	572.8235	515541
382.5	32.5	7133	456	32.5	19.250	16.250	0.60	60	1.176	563.8235	507441
383.0	33.0	6859	135	33.0	19.000	16.000	0.60	60	1.176	554.8235	499341
383.5	33.5	6592	17	33.5	18.750	15.750	0.60	60	1.176	545.8235	491241
384.0	34.0	6332	0	34.0	18.500	15.500	0.60	60	1.176	536.8235	483141
384.5	34.5	6078		34.5	18.250	15.250	0.60	60	1.176	527.8235	475041
385.0	35.0	5832		35.0	18.000	15.000	0.60	60	1.176	518.8235	466941

HOPKINTON EAST RETAINING WALL
STILLING BASIN WALL

EL.	HEIGHT FT	WIDTH in	d in	Icr IN^4	As1	Trans A	c	As2	Trans As2
350.0	0	73.000	70.000	150105	3.12	28.98	20.30	2.54	23.59
350.5	0.5	72.000	69.000	145205	3.12	28.98	20.12	2.54	23.59
351.0	1.0	71.000	68.000	140391	3.12	28.98	19.94	2.54	23.59
351.5	1.5	70.000	67.000	135664	3.12	28.98	19.76	2.54	23.59
352.0	2.0	69.000	66.000	131022	3.12	28.98	19.58	2.54	23.59
352.5	2.5	68.000	65.000	126467	3.12	28.98	19.39	2.54	23.59
353.0	3.0	67.000	64.000	121997	3.12	28.98	19.21	2.54	23.59
353.5	3.5	66.000	63.000	117613	3.12	28.98	19.02	2.54	23.59
354.0	4.0	65.000	62.000	113314	3.12	28.98	18.83	2.54	23.59
354.5	4.5	64.000	61.000	109101	3.12	28.98	18.64	2.54	23.59
355.0	5.0	63.000	60.000	104973	3.12	28.98	18.45	2.54	23.59
355.5	5.5	62.000	59.000	100930	3.12	28.98	18.26	2.54	23.59
356.0	6.0	61.000	58.000	96971	3.12	28.98	18.06	2.54	23.59
356.5	6.5	60.000	57.000	67199	3.12	28.98	17.87	2.54	23.59
357.0	7.0	59.000	56.000	64649	3.12	28.98	17.67	2.54	23.59
357.5	7.5	58.000	55.000	62150	3.12	28.98	17.47	2.54	23.59
358.0	8.0	57.000	54.000	59702	3.12	28.98	17.27	2.54	23.59
358.5	8.5	56.000	53.000	57305	3.12	28.98	17.07	2.54	23.59
359.0	9.0	55.000	52.000	54959	3.12	28.98	16.86	2.54	23.59
359.5	9.5	54.000	51.000	52664	3.12	28.98	16.65	2.54	23.59
360.0	10.0	53.000	50.000	50420	3.12	28.98	16.44	2.54	23.59
360.5	10.5	52.000	49.000	48227	3.12	28.98	16.23	2.54	23.59
361.0	11.0	51.000	48.000	46085	3.12	28.98	16.02	2.54	23.59
361.5	11.5	50.000	47.000	43993	3.12	28.98	15.80	2.54	23.59
362.0	12.0	49.000	46.000	41952	3.12	28.98	15.59	2.54	23.59
362.5	12.5	48.000	45.000	35539	2.83	26.29	12.02		
363.0	13.0	47.000	44.000	33827	2.83	26.29	11.87		
363.5	13.5	46.000	43.000	32160	2.83	26.29	11.71		
364.0	14.0	45.000	42.000	30537	2.83	26.29	11.55		
364.5	14.5	44.000	41.000	28958	2.83	26.29	11.39		
365.0	15.0	43.000	40.000	27423	2.83	26.29	11.23		
365.5	15.5	42.000	39.000	25933	2.83	26.29	11.06		
366.0	16.0	41.000	38.000	24486	2.83	26.29	10.90		
366.5	16.5	40.000	37.000	23083	2.83	26.29	10.73		
367.0	17.0	39.000	36.000	21723	2.83	26.29	10.56		
367.5	17.5	38.000	35.000	20408	2.83	26.29	10.38		
368.0	18.0	37.000	34.000	19135	2.83	26.29	10.21		
368.5	18.5	36.000	33.000	9345	1.27	11.80	7.13		
369.0	19.0	35.000	32.000	8745	1.27	11.80	7.01		
369.5	19.5	34.000	31.000	8166	1.27	11.80	6.89		
370.0	20.0	33.000	30.000	7607	1.27	11.80	6.76		
370.5	20.5	32.000	29.000	7069	1.27	11.80	6.63		
371.0	21.0	31.000	28.000	6552	1.27	11.80	6.50		
371.5	21.5	30.000	27.000	6055	1.27	11.80	6.37		
372.0	22.0	29.000	26.000	5578	1.27	11.80	6.23		
372.5	22.5	28.000	25.000	2706	0.60	5.57	4.38		
373.0	23.0	27.000	24.000	2481	0.60	5.57	4.28		
373.5	23.5	26.000	23.000	2266	0.60	5.57	4.18		
374.0	24.0	25.000	22.000	2061	0.60	5.57	4.08		
374.5	24.5	24.000	21.000	1867	0.60	5.57	3.98		
375.0	25.0	23.000	20.000	1682	0.60	5.57	3.87		
375.5	25.5	22.750	19.750	1637	0.60	5.57	3.84		
376.0	26.0	22.500	19.500	1593	0.60	5.57	3.82		
376.5	26.5	22.250	19.250	1550	0.60	5.57	3.79		
377.0	27.0	22.000	19.000	1507	0.60	5.57	3.76		

79.0	29.0	21.000	18.000	1342	0.60	5.57	3.65
79.5	29.5	20.750	17.750	1303	0.60	5.57	3.62
80.0	30.0	20.500	17.500	1263	0.60	5.57	3.59
80.5	30.5	20.250	17.250	1225	0.60	5.57	3.57
81.0	31.0	20.000	17.000	1187	0.60	5.57	3.54
81.5	31.5	19.750	16.750	1150	0.60	5.57	3.51
82.0	32.0	19.500	16.500	1113	0.60	5.57	3.48
82.5	32.5	19.250	16.250	1077	0.60	5.57	3.45
83.0	33.0	19.000	16.000	1042	0.60	5.57	3.42
83.5	33.5	18.750	15.750	1007	0.60	5.57	3.39
84.0	34.0	18.500	15.500	973	0.60	5.57	3.36
84.5	34.5	18.250	15.250	940	0.60	5.57	3.33
85.0	35.0	18.000	15.000	907	0.60	5.57	3.30

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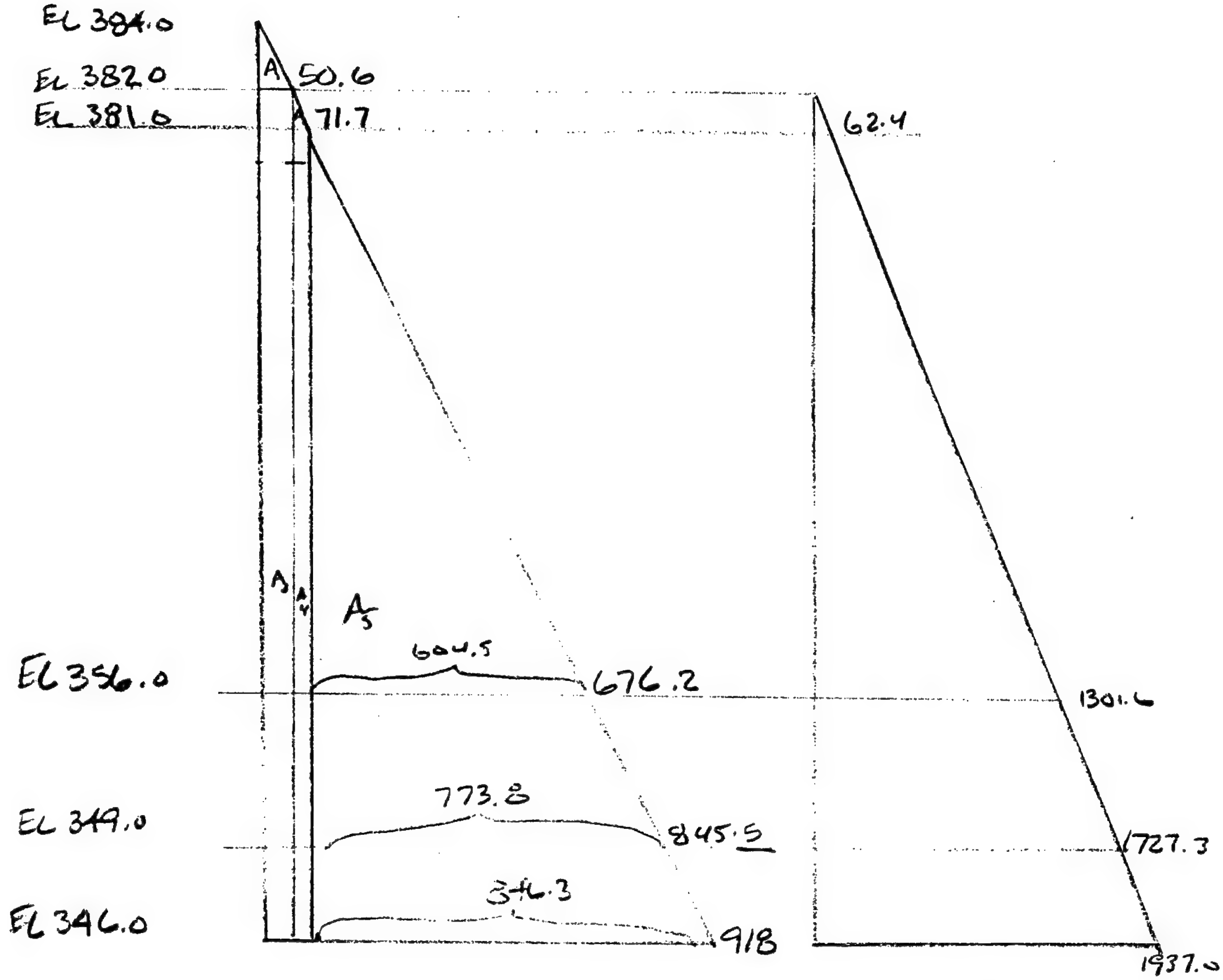
SUBJECT HOPKINTON EAST WALL
COMPUTATION OVERTURNING ANALYSIS
COMPUTED BY MAO CHECKED BY JTC DATE 1/20/84

ACTIVE SOIL PRESSURE.



APPROX PORE PRESSURE

CENTROID OF AREA. WALL A

EL 346

	AREA	A	Y	AY
A_1	1/2(50.6)(2)	32.17	36.67	1179.7
A_2	1/2(21.1)(1)	10.5	35.33	370.9
A_3	(36)(50.6)	1821.6	18	32788.8
A_4	(35)(21.1)	738.5	17.5	12923.8
A_5	(846)(35)1/2	14752.5	11.67	172161.7
		17355.3		219424.9

$\bar{Y} = 12.6'$

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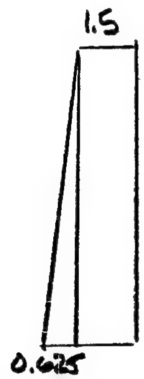
SUBJECT HOPKINGTON EAST WALL

COMPUTATION OVERTURNING ANALYSIS

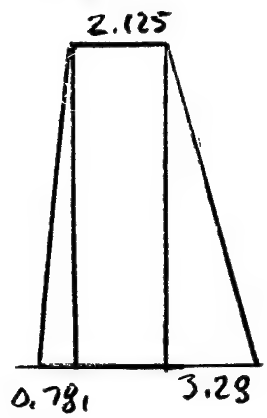
COMPUTED BY MAD CHECKED BY JAC DATE 1/26/94



C_1

A	Y	Ay
(15)(1.5)=22.5	.75	16.875
½(15)(.625)=4.68	1.708	8
27.18		24.87

$\bar{Y}$ 0.91



			$\bar{Y}$	$A\bar{Y}$
A_1	(3.28)(19.5)(½) =	31.98	2.18	69.7
A_2	(2.125)(19.5) =	41.43	4.43	179.8
A_3	(.781)(19.5) ½) =	7.61	5.67	43.1
		81.0		292.7

$\bar{Y} = 3.61$

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SUBJECT HOPKINTON EAST WALL

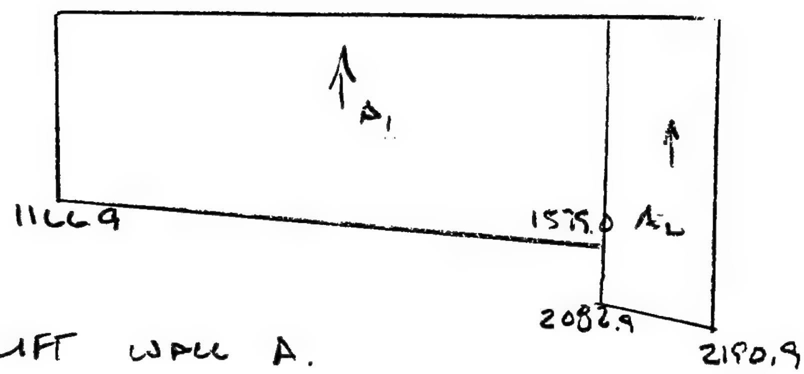
COMPUTATION OVERTURNING ANALYSIS

COMPUTED BY M. A. D. CHECKED BY JFC DATE 1/20/84

FORCE FROM WATER

A_A	17355.3	12.6	219424.9
A_W	(36)(1937)(1/2) = 34866	12	418392.0
	52221.3		637816.9

$\bar{Y} = 12.21$



UPLIFT WALL A.

$A_1 = \frac{1}{2}(1166.9 + 1579.0)(30) = 41188.5$

$\bar{Y} = \dfrac{30((2(1579.0)) + 1166.9)}{3\,(1166.9 + 1579.0)} = 15.7$

$\Big\}$ 648735

$A_2 = \frac{1}{2}(2082.9 + 2190.9)(3) = 6410.7$

$\bar{Y} = \dfrac{3(2(2190.9) + 2082.9)}{3(2082.9 + 2190.9)} + 30 \quad 31.52$

$\Big\}$ 202109.7

$\Sigma A \quad 47599.2 \qquad \Sigma A\bar{Y} \quad 850844$

$\bar{Y} = 17.87$

WT OF SOIL ASSUME FULL WIDTH

				A	$\bar{Y}$
ROCK	20.28	2	135	27378	23.55
GRAVEL	20.28	1	150	3042	
IMPERVIOUS	20.28	30.5	140	86595.6	
-CONC	1/2(3.28)(13.5)			-2494	
				89880.8	

TABLE OF FORCES FOR RETAINING WALL DESIGN

PROJECT: HOPKINTON EAST RETAINING WALL
DESCRIPTION: WALL A
LOCATION: HOPKINTON DAM, NH
DATE:

SIZE OF BASE: 33 FEET

ALL UNITS IN KIPS AND/OR FEET

NO.	HORIZ. RESIS	HORIZ. OVER	VERT. RESIS	VERT. OVER	MOMENT ARM	RESULTANT MOMENT
C1			12.15		12.1	147.0150
C2			4.08		11.52	47.0016
C3			20.25		15	303.7500
C4			4.73		31.5	148.9950
WS			89.88		23.55	2116.6740
Pa		52.2			12.21	-637.3620
U1				47.6	17.87	-850.6120
Pw1	9.91				5.7	56.4870
Pice		11.4			26.5	-302.1000
						0.0000
						0.0000
	SUM OF HORIZ	-53.69	SUM OF VERT	83.49	SUM OF MOMENTS	1029.85

ICE LOAD IN PSF 600

SUM OF MOMENTS OVERTURNING 1790.07
SUM OF MOMENTS RESISTING 2819.92

FACTOR OF SAFETY AGAINST OVERTURNING 1.58
LOCATION OF THE RESULTANT 12.33
ECCENTRICITY: 4.17
BEARING PRESSURE LEFT (KSF): 4.45
BEARING PRESSURE RIGHT (KSF): 0.61

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SUBJECT HOPKINTON EAST WALL

COMPUTATION OVERTURNING ANALYSIS WALL B

COMPUTED BY M.A.D. CHECKED BY JJC DATE 1/21/97

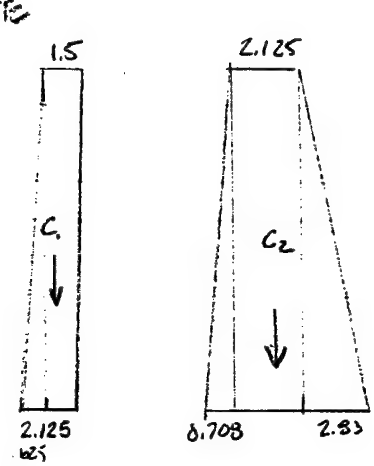
CENTROID OF AREA WALL SOIL PRESSURE WALL B.

EL 349.0

		A	$\bar{Y}$	$A\bar{Y}$
A_1	½(50.6)(2)	32.17	33.67	1083.2
A_2	½(21.1)(1)	10.5	32.33	339.5
A_3	33(50.6)	1669.8	16.5	27551.7
A_4	32(21.1)	675.2	16.0	10803.2
A_5	½(32)(773.3)	12380.8	10.67	132103.1
P_w	½(1727.3)(33)	28500.5	11	313505.5
		43269.0		485386.2

$\bar{Y} = 11.21$

CONCRETE



C_1 A_1 (1.5)(15) × .75 16.875

A_2 (.625)(15)(½) × 1.708 8

27.18 24.875

$\bar{Y} = 0.91$

			A	$\bar{Y}$	$A\bar{Y}$
C_2	A_1	(2.125)(17) =	36.125	3.89	140.53
	A_2	½(2.83)(17) =	24.06	1.89	45.5
	A_3	½(.708)(17) =	6.02	5.19	31.24
			66.205		217.26

$\bar{Y} = 3.28$

		F	$\bar{Y}$
C_1	(27.18)(.15)	4.08	10.93
C_2	(66.21)(.15)	9.93	11.38
C_3	(26.67)(.15)(4)	16.00	13.3
C_4	(10×3)(.15)	4.5	28.17

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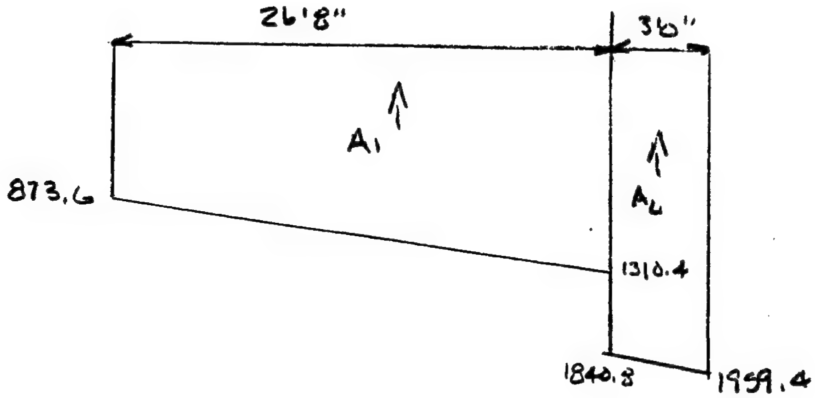
SUBJECT HOPKINTON EAST WALL
COMPUTATION OVERTURNING ANALYSIS WALL B
COMPUTED BY M.A.D. CHECKED BY JJC DATE 1/21/93

UPLIFT PRESSURE WALL B



A_1 $\frac{1}{2}(873.6+1310.4)(26.67) = 29123$

$\bar{Y} = \dfrac{26.67(2(1310.4)+873.6)}{3(873.6+1310.4)} = 14.22$ } $A\bar{Y} = 414138$

$A_2 = \frac{1}{2}(1840.8+1959.4)(3) = 5700$

$\bar{Y} = \dfrac{3(2(1959.4)+1840.8)}{3(1840.8+1959.4)} + 26.67 = 28.18$ } $= 160640$

$\Sigma A = 34823$ ΣAY 574778

$\bar{Y} = 16.5$

	F	Y
U =	34.8	16.5

	F	Y
$P_{W_1} = (.873)(14)(\frac{1}{2}) =$	6.11	4.67

					$\bar{Y}$
W_s = ROCK	17.83	2	135	4814.1	20.75
GRAVEL	17.83	1	150	2674.5	
IMPERVIOUS	17.83	28	140	69893.6	
− CONCRETE	½(17)(283)(.15)		−	(3608)	
				73774.2	
				= 73.8	

TABLE OF FORCES FOR RETAINING WALL DESIGN

PROJECT: HOPKINTON EAST RETAINING WALL
DESCRIPTION: WALL B
LOCATION: HOPKINTON DAM, NH
DATE:

SIZE OF BASE: 29.67 FEET

ALL UNITS IN KIPS AND/OR FEET

NO.	HORIZ. RESIS	HORIZ. OVER	VERT. RESIS	VERT. OVER	MOMENT ARM	RESULTANT MOMENT
C1			4.08		10.93	44.5944
C2			9.93		11.38	113.0034
C3			16		13.3	212.8000
C4			4.5		28.17	126.7650
WS			73.8		20.75	1531.3500
Pa		43.3			11.21	-485.3930
U1				34.8	16.5	-574.2000
Pw1	6.11				4.67	28.5337
Pice		11.4			23.5	-267.9000
						0.0000
						0.0000
	SUM OF HORIZ	-48.59	SUM OF VERT	73.51	SUM OF MOMENTS	729.55

ICE LOAD IN PSF 600

SUM OF MOMENTS OVERTURNING 1327.49
SUM OF MOMENTS RESISTING 2057.05

FACTOR OF SAFETY AGAINST OVERTURNING 1.55
LOCATION OF THE RESULTANT 9.92
ECCENTRICITY: 4.91
BEARING PRESSURE LEFT (KSF): 4.94
BEARING PRESSURE RIGHT (KSF): 0.02

SUBJECT HOPKINTON EAST WALL
COMPUTATION OVERTURNING ANALYSIS WALL C
COMPUTED BY M.A.D. CHECKED BY JJC DATE 1/21/93

WALL C

EL 356.0

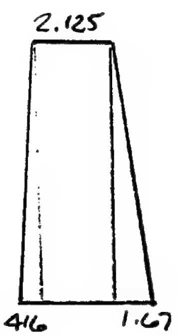
		A	$\bar{Y}$	$A\bar{Y}$
A_1	1/2 (50.6)(2)	= 32.17	26.67	858.0
A_2	1/2 (21.1)(1)	= 10.5	25.33	266.0
A_3	26 (50.6)	= 1315.6	13	17102.8
A_4	25 (21.1)	= 527.5	12.5	6593.8
A_5	1/2 (25) 604.5	= 7556.25	8.3	62716.9
A_6	1/2 (1301.6)(26)	= 16920.8	8.67	146696.4
		26362.8		234233.9

$\bar{Y} = 8.9'$

CONCRETE

$C_1 = \bar{Y} = 8.91$

C_2



		A	$\bar{Y}$	$A\bar{Y}$
A_1	(2.125)(10)	21.25	2.73	58.1
A_2	1/2(1.67)(10)	8.35	1.11	9.3
A_3	1/2(.416)(10)	2.08	3.93	8.18
		31.7		75.6

$\bar{Y} = 2.4'$

		F	$\bar{Y}$
C_1 =	(27.10)(.15)	4.08	9.42
C_2	(31.7)(.15)	4.8	9.6
C_3	(22)(4)(.15)	13.2	11
C_4	(10)(3)(.15)	4.5	23.5

						$\bar{Y}$
W_S =	ROCK	14.67	2	135	3960.9	17.67
	GRAVEL	14.67	1	150	2200.5	
	IMPERVIOUS	14.67	21	140	43129.8	
	— CONCRETE	1/2(1.67)(10)(.15)			(1252.5)	
					48038.7	

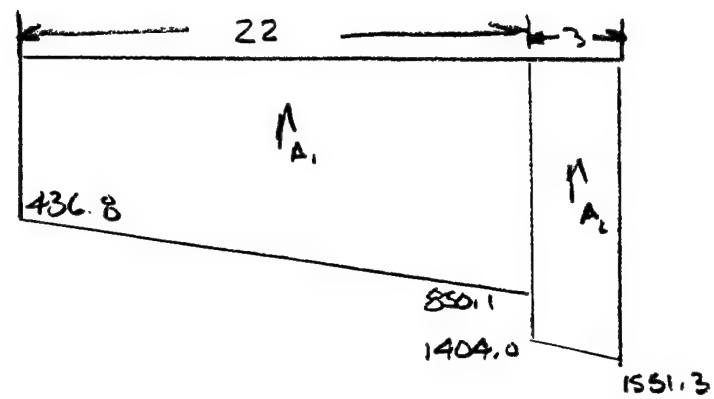
48.0K

NED FORM 223
27 Sept 49

NEW ENGLAND DIVISION
CORPS OF ENGINEERS, U.S. ARMY

SUBJECT HOPKINTON EAST WALL
COMPUTATION OVERTURNING ANALYSIS WALL C
COMPUTED BY M.A.D CHECKED BY JJC DATE 1/21/53

UPLIFT PRESSURE WALL C



$A_1 \quad \frac{1}{2}(436.8 + 850.1)(22) \qquad 14155.9$

$\bar{Y} = \dfrac{22\,(2(850.1) + 436.8)}{3\,(436.8 + 850.1)} \qquad 12.18$ $\Big\}$ 172384.7

$A_2 \quad \frac{1}{2}(1404.0 + 1551.3)(3) = 4432.95$

$\bar{Y} \quad \dfrac{3\,(2(1551.3) + 1404.)}{3\,(1404 + 1551.3)} \qquad 1.52$ $\Big\}$ 6759.9

$\Sigma A \quad 18588.9 \qquad \Sigma Ay \quad 179144.6$

$\bar{Y} = 9.6$

$F = 18.6 \quad \bar{Y} = 9.6$

$$\begin{array}{lcc} & F & \bar{Y} \\ P_w = 0.4368(7)(\tfrac{1}{2}) = & 1.53 & 2.33 \end{array}$$

Pice Mom arm = $(363 + {}^{15}/_{2}) - 356 \quad 16.5$

TABLE OF FORCES FOR RETAINING WALL DESIGN

PROJECT: HOPKINTON EAST RETAINING WALL
DESCRIPTION: WALL C
LOCATION: HOPKINTON DAM, NH
DATE:

SIZE OF BASE: 25 FEET

ALL UNITS IN KIPS AND/OR FEET

NO.	HORIZ. RESIS	HORIZ. OVER	VERT. RESIS	VERT. OVER	MOMENT ARM	RESULTANT MOMENT
C1			4.08		9.42	38.4336
C2			4.8		9.6	46.0800
C3			13.2		11	145.2000
C4			4.5		23.5	105.7500
WS			48		17.67	848.1600
Pa		26.4			8.9	-234.9600
U1				18.4	9.6	-176.6400
Pw1	1.53				2.33	3.5649
Pice		11.4			16.5	-188.1000
						0.0000
						0.0000
	SUM OF HORIZ	-36.27	SUM OF VERT	56.18	SUM OF MOMENTS	587.49

ICE LOAD IN PSF 600

SUM OF MOMENTS OVERTURNING 599.70
SUM OF MOMENTS RESISTING 1187.19

FACTOR OF SAFETY AGAINST OVERTURNING 1.98
LOCATION OF THE RESULTANT 10.46
ECCENTRICITY: 2.04
BEARING PRESSURE LEFT (KSF): 3.35
BEARING PRESSURE RIGHT (KSF): 1.15

APPENDIX B -- TILT PLATE AND SURVEY DATA

TILT PLATE DATA

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 1
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
11	30	89	30-Nov-89	-0.0119	-0.0038	0.0282	-0.0433	-0.0060	-0.0019	-0.0021	0.0000	0.0141	-0.0217	0.0179	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0202	0.0043	0.0281	-0.0438	-0.0101	0.0022	-0.0062	-0.0041	0.0141	-0.0219	0.0180	0.0001	-0.2349	0.0057
1	19	90	19-Jan-90	-0.0207	0.0056	0.0288	-0.0435	-0.0104	0.0028	-0.0066	-0.0045	0.0144	-0.0218	0.0181	0.0002	-0.2578	0.0115
3	2	90	02-Mar-90	-0.0156	0.0007	0.0288	-0.0434	-0.0078	0.0004	-0.0041	-0.0020	0.0144	-0.0217	0.0181	0.0002	-0.1146	0.0115
4	27	90	27-Apr-90	-0.0160	-0.0030	0.0266	-0.0452	-0.0080	-0.0015	-0.0033	-0.0012	0.0133	-0.0226	0.0180	0.0001	-0.0688	0.0057
5	14	90	14-May-90	-0.0161	-0.0020	0.0268	-0.0449	-0.0081	-0.0010	-0.0036	-0.0015	0.0134	-0.0225	0.0180	0.0001	-0.0859	0.0057
8	20	90	20-Aug-90	-0.0180	-0.0002	0.0265	-0.0444	-0.0090	-0.0001	-0.0045	-0.0024	0.0133	-0.0222	0.0178	-0.0001	-0.1375	-0.0057
10	29	90	29-Oct-90	-0.0162	0.0011	0.0282	-0.0432	-0.0081	0.0006	-0.0044	-0.0023	0.0141	-0.0216	0.0179	0.0000	-0.1318	0.0000
4	26	91	26-Apr-91	-0.0164	-0.0020	0.0261	-0.0440	-0.0082	-0.0010	-0.0036	-0.0015	0.0131	-0.0220	0.0176	-0.0003	-0.0859	-0.0172
8	7	91	07-Aug-91	-0.0157	-0.0040	0.0243	-0.0437	-0.0079	-0.0020	-0.0030	-0.0009	0.0122	-0.0219	0.0171	-0.0008	-0.0516	-0.0458
4	20	92	20-Apr-92	-0.0150	-0.0014	0.0257	-0.0417	-0.0075	-0.0007	-0.0034	-0.0013	0.0129	-0.0209	0.0169	-0.0010	-0.0745	-0.0573
3	28	94	28-Mar-94	-0.0212	0.0055	0.0248	-0.0403	-0.0106	0.0028	-0.0067	-0.0046	0.0124	-0.0202	0.0163	-0.0016	-0.2636	-0.0917
11	10	94	10-Nov-94	-0.0184	0.0027	0.0245	-0.0400	-0.0092	0.0014	-0.0053	-0.0032	0.0123	-0.0200	0.0162	-0.0017	-0.1833	-0.0974
3	30	95	30-Mar-95	-0.0184	0.0014	0.0237	-0.0405	-0.0092	0.0007	-0.0050	-0.0029	0.0119	-0.0203	0.0161	-0.0018	-0.1662	-0.1031
3	25	96	25-Mar-96	-0.0198	0.0017	0.0233	-0.0412	-0.0099	0.0009	-0.0054	-0.0033	0.0117	-0.0206	0.0162	-0.0017	-0.1891	-0.0974

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 2
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	0.0107	-0.0260	0.0097	-0.0248	0.0054	-0.0130	0.0092	0.0000	0.0049	-0.0124	0.0087	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	0.0010	-0.0167	0.0099	-0.0255	0.0005	-0.0084	0.0045	-0.0047	0.0050	-0.0128	0.0089	0.0002	-0.2693	0.0115
1	19	90	19-Jan-90	0.0004	-0.0152	0.0104	-0.0251	0.0002	-0.0076	0.0039	-0.0053	0.0052	-0.0126	0.0089	0.0002	-0.3037	0.0115
3	2	90	02-Mar-90	0.0045	-0.0196	0.0101	-0.0254	0.0023	-0.0098	0.0061	-0.0031	0.0051	-0.0127	0.0089	0.0002	-0.1776	0.0115
4	27	90	27-Apr-90	0.0079	-0.0268	0.0086	-0.0274	0.0040	-0.0134	0.0087	-0.0005	0.0043	-0.0137	0.0090	0.0003	-0.0286	0.0172
5	14	90	14-May-90	0.0081	-0.0280	0.0089	-0.0272	0.0041	-0.0140	0.0091	-0.0001	0.0045	-0.0136	0.0091	0.0004	-0.0057	0.0229
8	20	90	20-Aug-90	0.0082	-0.0264	0.0093	-0.0273	0.0041	-0.0132	0.0087	-0.0005	0.0047	-0.0137	0.0092	0.0005	-0.0286	0.0286
10	29	90	29-Oct-90	0.0100	-0.0252	0.0105	-0.0255	0.0050	-0.0126	0.0088	-0.0004	0.0053	-0.0128	0.0091	0.0004	-0.0229	0.0229
4	26	91	26-Apr-91	0.0082	-0.0266	0.0090	-0.0275	0.0041	-0.0133	0.0087	-0.0005	0.0045	-0.0138	0.0092	0.0005	-0.0286	0.0286
8	7	91	07-Aug-91	0.0081	-0.0278	0.0088	-0.0285	0.0041	-0.0139	0.0090	-0.0002	0.0044	-0.0143	0.0094	0.0007	-0.0115	0.0401
4	20	92	20-Apr-92	0.0100	-0.0260	0.0104	-0.0264	0.0050	-0.0130	0.0090	-0.0002	0.0052	-0.0132	0.0092	0.0005	-0.0115	0.0286
3	28	94	28-Mar-94	0.0013	-0.0170	0.0110	-0.0270	0.0007	-0.0085	0.0046	-0.0046	0.0055	-0.0135	0.0095	0.0008	-0.2636	0.0458
11	10	94	10-Nov-94	0.0053	-0.0214	0.0111	-0.0270	0.0027	-0.0107	0.0067	-0.0025	0.0056	-0.0135	0.0096	0.0009	-0.1432	0.0516
3	30	95	30-Mar-95	0.0055	-0.0220	0.0105	-0.0268	0.0028	-0.0110	0.0069	-0.0023	0.0053	-0.0134	0.0094	0.0007	-0.1318	0.0401
3	25	96	25-Mar-96	0.0026	-0.0204	0.0106	-0.0284	0.0013	-0.0102	0.0058	-0.0034	0.0053	-0.0142	0.0098	0.0011	-0.1948	0.0630

TILT PLATE DATA

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 3
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0177	0.0024	-0.0251	0.0098	-0.0089	0.0012	-0.0051	0.0000	-0.0126	0.0049	-0.0088	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0279	0.0125	-0.0251	0.0092	-0.0140	0.0063	-0.0102	-0.0051	-0.0126	0.0046	-0.0086	0.0002	-0.2922	0.0115
1	19	90	19-Jan-90	-0.0285	0.0140	-0.0249	0.0099	-0.0143	0.0070	-0.0107	-0.0056	-0.0125	0.0050	-0.0088	0.0000	-0.3209	0.0000
3	2	90	02-Mar-90	-0.0246	0.0095	-0.0257	0.0099	-0.0123	0.0048	-0.0086	-0.0035	-0.0129	0.0050	-0.0090	-0.0002	-0.2005	-0.0115
4	27	90	27-Apr-90	-0.0209	0.0025	-0.0274	0.0085	-0.0105	0.0013	-0.0059	-0.0008	-0.0137	0.0043	-0.0090	-0.0002	-0.0458	-0.0115
5	14	90	14-May-90	-0.0213	0.0028	-0.0271	0.0081	-0.0107	0.0014	-0.0061	-0.0010	-0.0136	0.0041	-0.0089	-0.0001	-0.0573	-0.0057
8	20	90	20-Aug-90	-0.0208	0.0030	-0.0258	0.0073	-0.0104	0.0015	-0.0060	-0.0009	-0.0129	0.0037	-0.0083	0.0005	-0.0516	0.0286
10	29	90	29-Oct-90	-0.0186	0.0040	-0.0240	0.0089	-0.0093	0.0020	-0.0057	-0.0006	-0.0120	0.0045	-0.0083	0.0005	-0.0344	0.0286
4	26	91	26-Apr-91	-0.0204	0.0026	-0.0259	0.0076	-0.0102	0.0013	-0.0058	-0.0007	-0.0130	0.0038	-0.0084	0.0004	-0.0401	0.0229
8	7	91	07-Aug-91	-0.0205	0.0011	-0.0268	0.0070	-0.0103	0.0006	-0.0055	-0.0004	-0.0134	0.0035	-0.0085	0.0003	-0.0229	0.0172
4	20	92	20-Apr-92	-0.0185	0.0028	-0.0251	0.0090	-0.0093	0.0014	-0.0054	-0.0003	-0.0126	0.0045	-0.0086	0.0002	-0.0172	0.0115
3	28	94	28-Mar-94	-0.0267	0.0111	-0.0246	0.0091	-0.0134	0.0056	-0.0095	-0.0044	-0.0123	0.0046	-0.0085	0.0003	-0.2521	0.0172
11	10	94	10-Nov-94	-0.0227	0.0071	-0.0253	0.0092	-0.0114	0.0036	-0.0075	-0.0024	-0.0127	0.0046	-0.0087	0.0001	-0.1375	0.0057
3	30	95	30-Mar-95	-0.0223	0.0059	-0.0255	0.0088	-0.0112	0.0030	-0.0071	-0.0020	-0.0128	0.0044	-0.0086	0.0002	-0.1146	0.0115
3	25	96	25-Mar-96	-0.0258	0.0086	-0.0266	0.0089	-0.0129	0.0043	-0.0086	-0.0035	-0.0133	0.0045	-0.0089	-0.0001	-0.2005	-0.0057

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 4
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0182	0.0030	-0.0086	-0.0069	-0.0091	0.0015	-0.0053	0.0000	-0.0043	-0.0035	-0.0004	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0289	0.0131	-0.0089	-0.0071	-0.0145	0.0066	-0.0106	-0.0053	-0.0045	-0.0036	-0.0005	-0.0001	-0.3037	-0.0057
1	19	90	19-Jan-90	-0.0293	0.0145	-0.0082	-0.0066	-0.0147	0.0073	-0.0110	-0.0057	-0.0041	-0.0033	-0.0004	0.0000	-0.3266	0.0000
3	2	90	02-Mar-90	-0.0247	0.0092	-0.0084	-0.0073	-0.0124	0.0046	-0.0085	-0.0032	-0.0042	-0.0037	-0.0003	0.0001	-0.1833	0.0057
4	27	90	27-Apr-90	-0.0215	0.0029	-0.0103	-0.0086	-0.0108	0.0015	-0.0062	-0.0009	-0.0052	-0.0043	-0.0005	-0.0001	-0.0516	-0.0057
5	14	90	14-May-90	-0.0215	0.0031	-0.0103	-0.0084	-0.0108	0.0016	-0.0062	-0.0009	-0.0052	-0.0042	-0.0005	-0.0001	-0.0516	-0.0057
8	20	90	20-Aug-90	-0.0210	0.0026	-0.0111	-0.0076	-0.0105	0.0013	-0.0059	-0.0006	-0.0056	-0.0038	-0.0009	-0.0005	-0.0344	-0.0286
10	29	90	29-Oct-90	-0.0184	0.0036	-0.0096	-0.0052	-0.0092	0.0018	-0.0055	-0.0002	-0.0048	-0.0026	-0.0011	-0.0007	-0.0115	-0.0401
4	26	91	26-Apr-91	-0.0204	0.0024	-0.0112	-0.0072	-0.0102	0.0012	-0.0057	-0.0004	-0.0056	-0.0036	-0.0010	-0.0006	-0.0229	-0.0344
8	7	91	07-Aug-91	-0.0207	0.0009	-0.0126	-0.0074	-0.0104	0.0005	-0.0055	-0.0002	-0.0063	-0.0037	-0.0013	-0.0009	-0.0115	-0.0516
4	20	92	20-Apr-92	-0.0185	0.0025	-0.0108	-0.0054	-0.0093	0.0013	-0.0053	0.0000	-0.0054	-0.0027	-0.0014	-0.0010	0.0000	-0.0573
3	28	94	28-Mar-94	-0.0250	0.0095	-0.0110	-0.0042	-0.0125	0.0048	-0.0087	-0.0034	-0.0055	-0.0021	-0.0017	-0.0013	-0.1948	-0.0745
11	10	94	10-Nov-94	-0.0214	0.0055	-0.0113	-0.0042	-0.0107	0.0028	-0.0068	-0.0015	-0.0057	-0.0021	-0.0018	-0.0014	-0.0859	-0.0802
3	30	95	30-Mar-95	-0.0214	0.0056	-0.0015	-0.0044	-0.0107	0.0028	-0.0068	-0.0015	-0.0008	-0.0022	0.0007	0.0011	-0.0859	0.0630
3	25	96	25-Mar-96	-0.0242	0.0066	-0.0127	-0.0054	-0.0121	0.0033	-0.0077	-0.0024	-0.0064	-0.0027	-0.0019	-0.0015	-0.1375	-0.0859

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 5
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0593	0.0451	0.0248	-0.0399	-0.0297	0.0226	-0.0262	0.0000	0.0124	-0.0200	0.0162	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0698	0.0551	0.0244	-0.0402	-0.0349	0.0276	-0.0313	-0.0051	0.0122	-0.0201	0.0162	0.0000	-0.2922	0.0000
1	19	90	19-Jan-90	-0.0705	0.0568	0.0248	-0.0393	-0.0353	0.0284	-0.0319	-0.0057	0.0124	-0.0197	0.0161	-0.0001	-0.3266	-0.0057
3	2	90	02-Mar-90	-0.0667	0.0521	0.0245	-0.0403	-0.0334	0.0261	-0.0298	-0.0036	0.0123	-0.0202	0.0163	0.0001	-0.2063	0.0057
4	27	90	27-Apr-90	-0.0652	0.0475	0.0230	-0.0418	-0.0326	0.0238	-0.0282	-0.0020	0.0115	-0.0209	0.0162	0.0000	-0.1146	0.0000
5	14	90	14-May-90	-0.0653	0.0480	0.0230	-0.0417	-0.0327	0.0240	-0.0284	-0.0022	0.0115	-0.0209	0.0162	0.0000	-0.1261	0.0000
8	20	90	20-Aug-90	-0.0662	0.0487	0.0229	-0.0415	-0.0331	0.0244	-0.0288	-0.0026	0.0115	-0.0208	0.0162	0.0000	-0.1490	0.0000
10	29	90	29-Oct-90	-0.0632	0.0496	0.0246	-0.0393	-0.0316	0.0248	-0.0282	-0.0020	0.0123	-0.0197	0.0160	-0.0002	-0.1146	-0.0115
4	26	91	26-Apr-91	-0.0653	0.0484	0.0234	-0.0415	-0.0327	0.0242	-0.0285	-0.0023	0.0117	-0.0208	0.0163	0.0001	-0.1318	0.0057
8	7	91	07-Aug-91	-0.0658	0.0472	0.0229	-0.0427	-0.0329	0.0236	-0.0283	-0.0021	0.0115	-0.0214	0.0165	0.0003	-0.1203	0.0172
4	20	92	20-Apr-92	-0.0635	0.0487	0.0248	-0.0408	-0.0318	0.0244	-0.0281	-0.0019	0.0124	-0.0204	0.0164	0.0002	-0.1089	0.0115
3	28	94	28-Mar-94	-0.0710	0.0559	0.0240	-0.0400	-0.0355	0.0280	-0.0318	-0.0056	0.0120	-0.0200	0.0160	-0.0002	-0.3209	-0.0115
11	10	94	10-Nov-94	-0.0670	0.0527	0.0241	-0.0400	-0.0335	0.0264	-0.0300	-0.0038	0.0121	-0.0200	0.0161	-0.0001	-0.2177	-0.0057
3	30	95	30-Mar-95	-0.0671	0.0515	0.0234	-0.0403	-0.0336	0.0258	-0.0297	-0.0035	0.0117	-0.0202	0.0160	-0.0002	-0.2005	-0.0115
3	25	96	25-Mar-96	-0.0698	0.0533	0.0228	-0.0404	-0.0349	0.0267	-0.0308	-0.0046	0.0114	-0.0202	0.0158	-0.0004	-0.2636	-0.0229

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 6
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0515	0.0364	-0.0458	0.0308	-0.0258	0.0182	-0.0220	0.0000	-0.0229	0.0154	-0.0192	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0621	0.0461	-0.0459	0.0300	-0.0311	0.0231	-0.0271	-0.0051	-0.0230	0.0150	-0.0190	0.0002	-0.2922	0.0115
1	19	90	19-Jan-90	-0.0628	0.0478	-0.0450	0.0302	-0.0314	0.0239	-0.0277	-0.0057	-0.0225	0.0151	-0.0188	0.0004	-0.3266	0.0229
3	2	90	02-Mar-90	-0.0592	0.0433	-0.0456	0.0300	-0.0296	0.0217	-0.0257	-0.0037	-0.0228	0.0150	-0.0189	0.0003	-0.2120	0.0172
4	27	90	27-Apr-90	-0.0563	0.0372	-0.0480	0.0290	-0.0282	0.0186	-0.0234	-0.0014	-0.0240	0.0145	-0.0193	-0.0001	-0.0802	-0.0057
5	14	90	14-May-90	-0.0564	0.0378	-0.0479	0.0294	-0.0282	0.0189	-0.0236	-0.0016	-0.0240	0.0147	-0.0194	-0.0002	-0.0917	-0.0115
8	20	90	20-Aug-90	-0.0578	0.0384	-0.0482	0.0293	-0.0289	0.0192	-0.0241	-0.0021	-0.0241	0.0147	-0.0194	-0.0002	-0.1203	-0.0115
10	29	90	29-Oct-90	-0.0547	0.0398	-0.0461	0.0313	-0.0274	0.0199	-0.0237	-0.0017	-0.0231	0.0157	-0.0194	-0.0002	-0.0974	-0.0115
4	26	91	26-Apr-91	-0.0571	0.0391	-0.0478	0.0300	-0.0286	0.0196	-0.0241	-0.0021	-0.0239	0.0150	-0.0195	-0.0003	-0.1203	-0.0172
8	7	91	07-Aug-91	-0.0573	0.0375	-0.0492	0.0295	-0.0287	0.0188	-0.0238	-0.0018	-0.0246	0.0148	-0.0197	-0.0005	-0.1031	-0.0286
4	20	92	20-Apr-92	-0.0550	0.0389	-0.0468	0.0307	-0.0275	0.0195	-0.0235	-0.0015	-0.0234	0.0154	-0.0194	-0.0002	-0.0859	-0.0115
3	28	94	28-Mar-94	-0.0608	0.0448	-0.0456	0.0297	-0.0304	0.0224	-0.0264	-0.0044	-0.0228	0.0149	-0.0189	0.0003	-0.2521	0.0172
11	10	94	10-Nov-94	-0.0570	0.0410	-0.0450	0.0295	-0.0285	0.0205	-0.0245	-0.0025	-0.0225	0.0148	-0.0187	0.0005	-0.1432	0.0286
3	30	95	30-Mar-95	-0.0571	0.0398	-0.0458	0.0291	-0.0286	0.0199	-0.0243	-0.0023	-0.0229	0.0146	-0.0188	0.0004	-0.1318	0.0229
3	25	96	25-Mar-96	-0.0595	0.0418	-0.0457	0.0280	-0.0298	0.0209	-0.0254	-0.0034	-0.0229	0.0140	-0.0185	0.0007	-0.1948	0.0401

TILT PLATE DATA

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 7
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	0.0195	-0.0345	-0.0167	0.0014	0.0098	-0.0173	0.0136	0.0000	-0.0084	0.0007	-0.0046	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	0.0092	-0.0248	-0.0173	0.0011	0.0046	-0.0124	0.0085	-0.0051	-0.0087	0.0006	-0.0047	-0.0001	-0.2922	-0.0057
1	19	90	19-Jan-90	0.0084	-0.0230	-0.0170	0.0020	0.0042	-0.0115	0.0079	-0.0057	-0.0085	0.0010	-0.0048	-0.0002	-0.3266	-0.0115
3	2	90	02-Mar-90	0.0121	-0.0277	-0.0175	0.0015	0.0061	-0.0139	0.0100	-0.0036	-0.0088	0.0008	-0.0048	-0.0002	-0.2063	-0.0115
4	27	90	27-Apr-90	0.0153	-0.0342	-0.0202	0.0011	0.0077	-0.0171	0.0124	-0.0012	-0.0101	0.0006	-0.0054	-0.0008	-0.0688	-0.0458
5	14	90	14-May-90	0.0156	-0.0341	-0.0201	0.0012	0.0078	-0.0171	0.0125	-0.0011	-0.0101	0.0006	-0.0054	-0.0008	-0.0630	-0.0458
8	20	90	20-Aug-90	0.0167	-0.0354	-0.0214	0.0023	0.0084	-0.0177	0.0131	-0.0005	-0.0107	0.0012	-0.0060	-0.0014	-0.0286	-0.0802
10	29	90	29-Oct-90	0.0199	-0.0345	-0.0194	0.0044	0.0100	-0.0173	0.0137	0.0001	-0.0097	0.0022	-0.0060	-0.0014	0.0057	-0.0802
4	26	91	26-Apr-91	0.0184	-0.0362	-0.0212	0.0028	0.0092	-0.0181	0.0137	0.0001	-0.0106	0.0014	-0.0060	-0.0014	0.0057	-0.0802
8	7	91	07-Aug-91	0.0184	-0.0380	-0.0217	0.0016	0.0092	-0.0190	0.0141	0.0005	-0.0109	0.0008	-0.0059	-0.0013	0.0286	-0.0745
4	20	92	20-Apr-92	0.0202	-0.0363	-0.0199	0.0034	0.0101	-0.0182	0.0142	0.0006	-0.0100	0.0017	-0.0059	-0.0013	0.0344	-0.0745
3	28	94	28-Mar-94	0.0129	-0.0290	-0.0190	0.0027	0.0065	-0.0145	0.0105	-0.0031	-0.0095	0.0014	-0.0055	-0.0009	-0.1776	-0.0516
11	10	94	10-Nov-94	0.0169	-0.0326	-0.0187	0.0024	0.0085	-0.0163	0.0124	-0.0012	-0.0094	0.0012	-0.0053	-0.0007	-0.0688	-0.0401
3	30	95	30-Mar-95	0.0160	-0.0340	-0.0198	0.0014	0.0080	-0.0170	0.0125	-0.0011	-0.0099	0.0007	-0.0053	-0.0007	-0.0630	-0.0401
3	25	96	25-Mar-96	0.0145	-0.0323	-0.0203	0.0021	0.0073	-0.0162	0.0118	-0.0018	-0.0102	0.0011	-0.0057	-0.0011	-0.1031	-0.0630

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 8
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	0.0272	-0.0423	-0.0152	0.0002	0.0136	-0.0212	0.0174	0.0000	-0.0076	0.0001	-0.0039	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	0.0174	-0.0332	-0.0150	-0.0008	0.0087	-0.0166	0.0127	-0.0047	-0.0075	-0.0004	-0.0036	0.0003	-0.2693	0.0172
1	19	90	19-Jan-90	0.0172	-0.0318	-0.0146	0.0000	0.0086	-0.0159	0.0123	-0.0051	-0.0073	0.0000	-0.0037	0.0002	-0.2922	0.0115
3	2	90	02-Mar-90	0.0218	-0.0375	-0.0146	-0.0012	0.0109	-0.0188	0.0149	-0.0025	-0.0073	-0.0006	-0.0034	0.0005	-0.1432	0.0286
4	27	90	27-Apr-90	0.0250	-0.0438	-0.0170	-0.0021	0.0125	-0.0219	0.0172	-0.0002	-0.0085	-0.0011	-0.0037	0.0002	-0.0115	0.0115
5	14	90	14-May-90	0.0249	-0.0435	-0.0170	-0.0019	0.0125	-0.0218	0.0172	-0.0002	-0.0085	-0.0010	-0.0038	0.0001	-0.0115	0.0057
8	20	90	20-Aug-90	0.0249	-0.0435	-0.0184	-0.0004	0.0125	-0.0218	0.0172	-0.0002	-0.0092	-0.0002	-0.0045	-0.0006	-0.0115	-0.0344
10	29	90	29-Oct-90	0.0273	-0.0419	-0.0165	0.0018	0.0137	-0.0210	0.0174	0.0000	-0.0083	0.0009	-0.0046	-0.0007	0.0000	-0.0401
4	26	91	26-Apr-91	0.0261	-0.0438	-0.0171	-0.0011	0.0131	-0.0219	0.0175	0.0001	-0.0086	-0.0006	-0.0040	-0.0001	0.0057	-0.0057
8	7	91	07-Aug-91	0.0262	-0.0459	-0.0193	-0.0007	0.0131	-0.0230	0.0181	0.0007	-0.0097	-0.0004	-0.0047	-0.0008	0.0401	-0.0458
4	20	92	20-Apr-92	0.0277	-0.0439	-0.0173	0.0010	0.0139	-0.0220	0.0180	0.0006	-0.0087	0.0005	-0.0046	-0.0007	0.0344	-0.0401
3	28	94	28-Mar-94	0.0206	-0.0364	-0.0180	0.0020	0.0103	-0.0182	0.0143	-0.0031	-0.0090	0.0010	-0.0050	-0.0011	-0.1776	-0.0630
11	10	94	10-Nov-94	0.0241	-0.0400	-0.0187	0.0025	0.0121	-0.0200	0.0161	-0.0013	-0.0094	0.0013	-0.0054	-0.0015	-0.0745	-0.0859
3	30	95	30-Mar-95	0.0236	-0.0415	-0.0194	0.0014	0.0118	-0.0208	0.0163	-0.0011	-0.0097	0.0007	-0.0052	-0.0013	-0.0630	-0.0745
3	25	96	25-Mar-96	0.0229	-0.0405	-0.0193	0.0015	0.0115	-0.0203	0.0159	-0.0015	-0.0097	0.0008	-0.0053	-0.0014	-0.0859	-0.0802

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 9
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0265	0.0112	0.0130	-0.0280	-0.0133	0.0056	-0.0095	0.0000	0.0065	-0.0140	0.0103	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0360	0.0198	0.0128	-0.0283	-0.0180	0.0099	-0.0140	-0.0045	0.0064	-0.0142	0.0103	0.0000	-0.2578	0.0000
1	19	90	19-Jan-90	-0.0365	0.0215	0.0132	-0.0277	-0.0183	0.0108	-0.0146	-0.0051	0.0066	-0.0139	0.0103	0.0000	-0.2922	0.0000
3	2	90	02-Mar-90	-0.0331	0.0170	0.0123	-0.0279	-0.0166	0.0085	-0.0126	-0.0031	0.0062	-0.0140	0.0101	-0.0002	-0.1776	-0.0115
4	27	90	27-Apr-90	-0.0296	0.0106	0.0099	-0.0288	-0.0148	0.0053	-0.0101	-0.0006	0.0050	-0.0144	0.0097	-0.0006	-0.0344	-0.0344
5	14	90	14-May-90	-0.0297	0.0107	0.0100	-0.0290	-0.0149	0.0054	-0.0102	-0.0007	0.0050	-0.0145	0.0098	-0.0005	-0.0401	-0.0286
8	20	90	20-Aug-90	-0.0296	0.0109	0.0098	-0.0283	-0.0148	0.0055	-0.0102	-0.0007	0.0049	-0.0142	0.0096	-0.0007	-0.0401	-0.0401
10	29	90	29-Oct-90	-0.0270	0.0121	0.0119	-0.0266	-0.0135	0.0061	-0.0098	-0.0003	0.0060	-0.0133	0.0097	-0.0006	-0.0172	-0.0344
4	26	91	26-Apr-91	-0.0289	0.0108	0.0104	-0.0281	-0.0145	0.0054	-0.0100	-0.0005	0.0052	-0.0141	0.0097	-0.0006	-0.0286	-0.0344
8	7	91	07-Aug-91	-0.0298	0.0096	0.0096	-0.0294	-0.0149	0.0048	-0.0099	-0.0004	0.0048	-0.0147	0.0098	-0.0005	-0.0229	-0.0286
4	20	92	20-Apr-92	-0.0280	0.0115	0.0115	-0.0278	-0.0140	0.0058	-0.0099	-0.0004	0.0058	-0.0139	0.0099	-0.0004	-0.0229	-0.0229
3	28	94	28-Mar-94	-0.0350	0.0188	0.0118	-0.0282	-0.0175	0.0094	-0.0135	-0.0040	0.0059	-0.0141	0.0100	-0.0003	-0.2292	-0.0172
11	10	94	10-Nov-94	-0.0316	0.0157	0.0120	-0.0282	-0.0158	0.0079	-0.0119	-0.0024	0.0060	-0.0141	0.0101	-0.0002	-0.1375	-0.0115
3	30	95	30-Mar-95	-0.0325	0.0147	0.0112	-0.0290	-0.0163	0.0074	-0.0119	-0.0024	0.0056	-0.0145	0.0101	-0.0002	-0.1375	-0.0115
3	25	96	25-Mar-96	-0.0338	0.0161	0.0111	-0.0291	-0.0169	0.0081	-0.0125	-0.0030	0.0056	-0.0146	0.0101	-0.0002	-0.1719	-0.0115

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 10
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0484	0.0335	-0.0696	0.0543	-0.0242	0.0168	-0.0205	0.0000	-0.0348	0.0272	-0.0310	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0564	0.0406	-0.0701	0.0543	-0.0282	0.0203	-0.0243	-0.0038	-0.0351	0.0272	-0.0312	-0.0002	-0.2177	-0.0115
1	19	90	19-Jan-90	-0.0565	0.0418	-0.0697	0.0548	-0.0283	0.0209	-0.0246	-0.0041	-0.0349	0.0274	-0.0312	-0.0002	-0.2349	-0.0115
3	2	90	02-Mar-90	-0.0531	0.0375	-0.0700	0.0543	-0.0266	0.0188	-0.0227	-0.0022	-0.0350	0.0272	-0.0311	-0.0001	-0.1261	-0.0057
4	27	90	27-Apr-90	-0.0511	0.0323	-0.0726	0.0533	-0.0256	0.0162	-0.0209	-0.0004	-0.0363	0.0267	-0.0315	-0.0005	-0.0229	-0.0286
5	14	90	14-May-90	-0.0512	0.0326	-0.0727	0.0539	-0.0256	0.0163	-0.0210	-0.0005	-0.0364	0.0270	-0.0317	-0.0007	-0.0286	-0.0401
8	20	90	20-Aug-90	-0.0517	0.0331	-0.0736	0.0551	-0.0259	0.0166	-0.0213	-0.0008	-0.0368	0.0276	-0.0322	-0.0012	-0.0458	-0.0688
10	29	90	29-Oct-90	-0.0490	0.0346	-0.0714	0.0565	-0.0245	0.0173	-0.0209	-0.0004	-0.0357	0.0283	-0.0320	-0.0010	-0.0229	-0.0573
4	26	91	26-Apr-91	-0.0508	0.0330	-0.0731	0.0552	-0.0254	0.0165	-0.0210	-0.0005	-0.0366	0.0276	-0.0321	-0.0011	-0.0286	-0.0630
8	7	91	07-Aug-91	-0.0516	0.0322	-0.0746	0.0546	-0.0258	0.0161	-0.0210	-0.0005	-0.0373	0.0273	-0.0323	-0.0013	-0.0286	-0.0745
4	20	92	20-Apr-92	-0.0502	0.0338	-0.0726	0.0561	-0.0251	0.0169	-0.0210	-0.0005	-0.0363	0.0281	-0.0322	-0.0012	-0.0286	-0.0688
3	28	94	28-Mar-94	-0.0560	0.0401	-0.0720	0.0561	-0.0280	0.0201	-0.0241	-0.0036	-0.0360	0.0281	-0.0321	-0.0011	-0.2063	-0.0630
11	10	94	10-Nov-94	-0.0546	0.0388	-0.0725	0.0562	-0.0273	0.0194	-0.0234	-0.0029	-0.0363	0.0281	-0.0322	-0.0012	-0.1662	-0.0688
3	30	95	30-Mar-95	-0.0554	0.0380	-0.0730	0.0555	-0.0277	0.0190	-0.0234	-0.0029	-0.0365	0.0278	-0.0322	-0.0012	-0.1662	-0.0688
3	25	96	25-Mar-96	-0.0571	0.0394	-0.0735	0.0555	-0.0286	0.0197	-0.0242	-0.0037	-0.0368	0.0278	-0.0323	-0.0013	-0.2120	-0.0745

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 11
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0541	0.0389	-0.0022	-0.0132	-0.0271	0.0195	-0.0233	0.0000	-0.0011	-0.0066	0.0028	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0605	0.0447	-0.0031	-0.0125	-0.0303	0.0224	-0.0264	-0.0031	-0.0016	-0.0063	0.0024	-0.0004	-0.1776	-0.0229
1	19	90	19-Jan-90	-0.0613	0.0465	-0.0027	-0.0122	-0.0307	0.0233	-0.0270	-0.0037	-0.0014	-0.0061	0.0024	-0.0004	-0.2120	-0.0229
3	2	90	02-Mar-90	-0.0589	0.0431	-0.0025	-0.0135	-0.0295	0.0216	-0.0256	-0.0023	-0.0013	-0.0068	0.0028	0.0000	-0.1318	0.0000
4	27	90	27-Apr-90	-0.0577	0.0385	-0.0039	-0.0154	-0.0289	0.0193	-0.0241	-0.0008	-0.0020	-0.0077	0.0029	0.0001	-0.0458	0.0057
5	14	90	14-May-90	-0.0577	0.0389	-0.0037	-0.0152	-0.0289	0.0195	-0.0242	-0.0009	-0.0019	-0.0076	0.0029	0.0001	-0.0516	0.0057
8	20	90	30-Mar-00	-0.0587	0.0398	-0.0040	-0.0150	-0.0294	0.0199	-0.0247	-0.0014	-0.0020	-0.0075	0.0028	0.0000	-0.0802	0.0000
10	29	90	29-Oct-90	-0.0556	0.0407	-0.0019	-0.0130	-0.0278	0.0204	-0.0241	-0.0008	-0.0010	-0.0065	0.0028	0.0000	-0.0458	0.0000
4	26	91	26-Apr-91	-0.0580	0.0399	-0.0038	-0.0142	-0.0290	0.0200	-0.0245	-0.0012	-0.0019	-0.0071	0.0026	-0.0002	-0.0688	-0.0115
8	7	91	07-Aug-91	-0.0581	0.0381	-0.0042	-0.0158	-0.0291	0.0191	-0.0241	-0.0008	-0.0021	-0.0079	0.0029	0.0001	-0.0458	0.0057
4	20	92	20-Apr-92	-0.0564	0.0398	-0.0022	-0.0142	-0.0282	0.0199	-0.0241	-0.0008	-0.0011	-0.0071	0.0030	0.0002	-0.0458	0.0115
3	28	94	28-Mar-94	-0.0602	0.0442	-0.0010	-0.0145	-0.0301	0.0221	-0.0261	-0.0028	-0.0005	-0.0073	0.0034	0.0006	-0.1604	0.0344
11	10	94	10-Nov-94	-0.0583	0.0420	-0.0010	-0.0149	-0.0292	0.0210	-0.0251	-0.0018	-0.0005	-0.0075	0.0035	0.0007	-0.1031	0.0401
3	30	95	30-Mar-95	-0.0590	0.0414	-0.0015	-0.0160	-0.0295	0.0207	-0.0251	-0.0018	-0.0008	-0.0080	0.0036	0.0008	-0.1031	0.0458
3	25	96	25-Mar-96	-0.0601	0.0426	-0.0012	-0.0165	-0.0301	0.0213	-0.0257	-0.0024	-0.0006	-0.0083	0.0039	0.0011	-0.1375	0.0630

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 12
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0032	-0.0118	-0.0092	-0.0068	-0.0016	-0.0059	0.0022	0.0000	-0.0046	-0.0034	-0.0006	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0062	-0.0095	-0.0098	-0.0065	-0.0031	-0.0048	0.0009	-0.0013	-0.0049	-0.0033	-0.0008	-0.0002	-0.0745	-0.0115
1	19	90	19-Jan-90	-0.0058	-0.0088	-0.0089	-0.0066	-0.0029	-0.0044	0.0008	-0.0014	-0.0045	-0.0033	-0.0006	0.0000	-0.0802	0.0000
3	2	90	02-Mar-90	-0.0048	-0.0111	-0.0090	-0.0066	-0.0024	-0.0056	0.0016	-0.0006	-0.0045	-0.0033	-0.0006	0.0000	-0.0344	0.0000
4	27	90	27-Apr-90	-0.0045	-0.0147	-0.0101	-0.0096	-0.0023	-0.0074	0.0026	0.0004	-0.0051	-0.0048	-0.0002	0.0004	0.0229	0.0229
5	14	90	14-May-90	-0.0043	-0.0144	-0.0098	-0.0102	-0.0022	-0.0072	0.0025	0.0003	-0.0049	-0.0051	0.0001	0.0007	0.0172	0.0401
8	20	90	20-Aug-90	-0.0040	-0.0149	-0.0091	-0.0102	-0.0020	-0.0075	0.0028	0.0006	-0.0046	-0.0051	0.0002	0.0008	0.0344	0.0458
10	29	90	29-Oct-90	-0.0023	-0.0133	-0.0069	-0.0081	-0.0012	-0.0067	0.0028	0.0006	-0.0035	-0.0041	0.0003	0.0009	0.0344	0.0516
4	26	91	26-Apr-91	-0.0032	-0.0148	-0.0086	-0.0097	-0.0016	-0.0074	0.0029	0.0007	-0.0043	-0.0049	0.0003	0.0009	0.0401	0.0516
8	7	91	07-Aug-91	-0.0031	-0.0168	-0.0101	-0.0102	-0.0016	-0.0084	0.0034	0.0012	-0.0051	-0.0051	0.0000	0.0006	0.0688	0.0344
4	20	92	20-Apr-92	-0.0009	-0.0153	-0.0085	-0.0082	-0.0005	-0.0077	0.0036	0.0014	-0.0043	-0.0041	-0.0001	0.0005	0.0802	0.0286
3	28	94	28-Mar-94	-0.0019	-0.0138	-0.0100	-0.0067	-0.0010	-0.0069	0.0030	0.0008	-0.0050	-0.0034	-0.0008	-0.0002	0.0458	-0.0115
11	10	94	10-Nov-94	-0.0022	-0.0153	-0.0099	-0.0064	-0.0011	-0.0077	0.0033	0.0011	-0.0050	-0.0032	-0.0009	-0.0003	0.0630	-0.0172
3	30	95	30-Mar-95	-0.0010	-0.0157	-0.0103	-0.0070	-0.0005	-0.0079	0.0037	0.0015	-0.0052	-0.0035	-0.0009	-0.0003	0.0859	-0.0172
3	25	96	25-Mar-96	-0.0016	-0.0157	-0.0106	-0.0071	-0.0008	-0.0079	0.0036	0.0014	-0.0053	-0.0036	-0.0009	-0.0003	0.0802	-0.0172

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 13
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	0.0219	-0.0431	0.0208	-0.0328	0.0110	-0.0216	0.0163	0.0000	0.0104	-0.0164	0.0134	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	0.0198	-0.0416	0.0200	-0.0325	0.0099	-0.0208	0.0154	-0.0009	0.0100	-0.0163	0.0132	-0.0002	-0.0516	-0.0115
1	19	90	19-Jan-90	0.0192	-0.0402	0.0205	-0.0322	0.0096	-0.0201	0.0149	-0.0014	0.0103	-0.0161	0.0132	-0.0002	-0.0802	-0.0115
3	2	90	02-Mar-90	0.0197	-0.0416	0.0206	-0.0330	0.0099	-0.0208	0.0154	-0.0009	0.0103	-0.0165	0.0134	0.0000	-0.0516	0.0000
4	27	90	27-Apr-90	0.0197	-0.0451	0.0194	-0.0353	0.0099	-0.0226	0.0163	0.0000	0.0097	-0.0177	0.0137	0.0003	0.0000	0.0172
5	14	90	14-May-90	0.0196	-0.0444	0.0196	-0.0352	0.0098	-0.0222	0.0160	-0.0003	0.0098	-0.0176	0.0137	0.0003	-0.0172	0.0172
8	20	90	20-Aug-90	0.0198	-0.0448	0.0203	-0.0360	0.0099	-0.0224	0.0162	-0.0001	0.0102	-0.0180	0.0141	0.0007	-0.0057	0.0401
10	29	90	29-Oct-90	0.0222	-0.0430	0.0225	-0.0339	0.0111	-0.0215	0.0163	0.0000	0.0113	-0.0170	0.0142	0.0008	0.0000	0.0458
4	26	91	26-Apr-91	0.0206	-0.0448	0.0202	-0.0351	0.0103	-0.0224	0.0164	0.0001	0.0101	-0.0176	0.0139	0.0005	0.0057	0.0286
8	7	91	07-Aug-91	0.0212	-0.0476	0.0181	-0.0351	0.0106	-0.0238	0.0172	0.0009	0.0091	-0.0176	0.0134	0.0000	0.0516	0.0000
4	20	92	20-Apr-92	0.0231	-0.0458	0.0197	-0.0330	0.0116	-0.0229	0.0173	0.0010	0.0099	-0.0165	0.0132	-0.0002	0.0573	-0.0115
3	28	94	28-Mar-94	0.0219	-0.0442	0.0189	-0.0320	0.0110	-0.0221	0.0166	0.0003	0.0095	-0.0160	0.0128	-0.0006	0.0172	-0.0344
11	10	94	10-Nov-94	0.0234	-0.0454	0.0184	-0.0318	0.0117	-0.0227	0.0172	0.0009	0.0092	-0.0159	0.0126	-0.0008	0.0516	-0.0458
3	30	95	30-Mar-95	0.0230	-0.0462	0.0179	-0.0321	0.0115	-0.0231	0.0173	0.0010	0.0090	-0.0161	0.0126	-0.0008	0.0573	-0.0458
3	25	96	25-Mar-96	0.0227	-0.0463	0.0170	-0.0327	0.0114	-0.0232	0.0173	0.0010	0.0085	-0.0164	0.0125	-0.0009	0.0573	-0.0516

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 14
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0631	0.0477	0.0007	-0.0161	-0.0316	0.0239	-0.0278	0.0000	0.0004	-0.0081	0.0043	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0632	0.0472	0.0002	-0.0161	-0.0316	0.0236	-0.0276	0.0002	0.0001	-0.0081	0.0041	-0.0002	0.0115	-0.0115
1	19	90	19-Jan-90	-0.0629	0.0479	0.0004	-0.0154	-0.0315	0.0240	-0.0278	0.0000	0.0002	-0.0077	0.0040	-0.0003	0.0000	-0.0172
3	2	90	02-Mar-90	-0.0640	0.0478	0.0000	-0.0161	-0.0320	0.0239	-0.0280	-0.0002	0.0000	-0.0081	0.0041	-0.0002	-0.0115	-0.0115
4	27	90	27-Apr-90	-0.0659	0.0464	-0.0021	-0.0174	-0.0330	0.0232	-0.0281	-0.0003	-0.0011	-0.0087	0.0038	-0.0005	-0.0172	-0.0286
5	14	90	14-May-90	-0.0656	0.0468	-0.0018	-0.0175	-0.0328	0.0234	-0.0281	-0.0003	-0.0009	-0.0088	0.0040	-0.0003	-0.0172	-0.0172
8	20	90	20-Aug-90	-0.0659	0.0469	-0.0026	-0.0169	-0.0330	0.0235	-0.0283	-0.0005	-0.0013	-0.0085	0.0036	-0.0007	-0.0286	-0.0401
10	29	90	29-Oct-90	-0.0641	0.0491	-0.0008	-0.0143	-0.0321	0.0246	-0.0284	-0.0006	-0.0004	-0.0072	0.0034	-0.0009	-0.0344	-0.0516
4	26	91	26-Apr-91	-0.0657	0.0474	-0.0021	-0.0165	-0.0329	0.0237	-0.0283	-0.0005	-0.0011	-0.0083	0.0036	-0.0007	-0.0286	-0.0401
8	7	91	07-Aug-91	-0.0662	0.0458	-0.0028	-0.0177	-0.0331	0.0229	-0.0280	-0.0002	-0.0014	-0.0089	0.0038	-0.0005	-0.0115	-0.0286
4	20	92	20-Apr-92	-0.0643	0.0476	-0.0016	-0.0152	-0.0322	0.0238	-0.0280	-0.0002	-0.0008	-0.0076	0.0034	-0.0009	-0.0115	-0.0516
3	28	94	28-Mar-94	-0.0632	0.0467	0.0000	-0.0163	-0.0316	0.0234	-0.0275	0.0003	0.0000	-0.0082	0.0041	-0.0002	0.0172	-0.0115
11	10	94	10-Nov-94	-0.0637	0.0474	0.0000	-0.0169	-0.0319	0.0237	-0.0278	0.0000	0.0000	-0.0085	0.0043	0.0000	0.0000	0.0000
3	30	95	30-Mar-95	-0.0645	0.0465	-0.0002	-0.0175	-0.0323	0.0233	-0.0278	0.0000	-0.0001	-0.0088	0.0044	0.0001	0.0000	0.0057
3	25	96	25-Mar-96	-0.0642	0.0466	-0.0007	-0.0175	-0.0321	0.0233	-0.0277	0.0001	-0.0004	-0.0088	0.0042	-0.0001	0.0057	-0.0057

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 15
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0750	0.0599	-0.0112	-0.0045	-0.0375	0.0300	-0.0338	0.0000	-0.0056	-0.0023	-0.0017	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0823	0.0670	-0.0115	-0.0046	-0.0412	0.0335	-0.0374	-0.0036	-0.0058	-0.0023	-0.0018	-0.0001	-0.2063	-0.0057
1	19	90	19-Jan-90	-0.0815	0.0669	-0.0110	-0.0041	-0.0408	0.0335	-0.0372	-0.0034	-0.0055	-0.0021	-0.0017	0.0000	-0.1948	0.0000
3	2	90	02-Mar-90	-0.0782	0.0626	-0.0112	-0.0049	-0.0391	0.0313	-0.0352	-0.0014	-0.0056	-0.0025	-0.0016	0.0001	-0.0802	0.0057
4	27	90	27-Apr-90	-0.0784	0.0595	-0.0131	-0.0063	-0.0392	0.0298	-0.0345	-0.0007	-0.0066	-0.0032	-0.0017	0.0000	-0.0401	0.0000
5	14	90	14-May-90	-0.0781	0.0598	-0.0127	-0.0061	-0.0391	0.0299	-0.0345	-0.0007	-0.0064	-0.0031	-0.0017	0.0000	-0.0401	0.0000
8	20	90	20-Aug-90	-0.0784	0.0597	-0.0133	-0.0058	-0.0392	0.0299	-0.0346	-0.0008	-0.0067	-0.0029	-0.0019	-0.0002	-0.0458	-0.0115
10	29	90	29-Oct-90	-0.0756	0.0607	-0.0113	-0.0042	-0.0378	0.0304	-0.0341	-0.0003	-0.0057	-0.0021	-0.0018	-0.0001	-0.0172	-0.0057
4	26	91	26-Apr-91	-0.0769	0.0594	-0.0132	-0.0050	-0.0385	0.0297	-0.0341	-0.0003	-0.0066	-0.0025	-0.0021	-0.0004	-0.0172	-0.0229
8	7	91	07-Aug-91	-0.0764	0.0568	-0.0144	-0.0056	-0.0382	0.0284	-0.0333	0.0005	-0.0072	-0.0028	-0.0022	-0.0005	0.0286	-0.0286
4	20	92	20-Apr-92	-0.0740	0.0576	-0.0125	-0.0043	-0.0370	0.0288	-0.0329	0.0009	-0.0063	-0.0022	-0.0021	-0.0004	0.0516	-0.0229
3	28	94	28-Mar-94	-0.0787	0.0633	-0.0128	-0.0033	-0.0394	0.0317	-0.0356	-0.0018	-0.0064	-0.0017	-0.0024	-0.0007	-0.1031	-0.0401
11	10	94	10-Nov-94	-0.0768	0.0612	-0.0127	-0.0030	-0.0384	0.0306	-0.0345	-0.0007	-0.0064	-0.0015	-0.0025	-0.0008	-0.0401	-0.0458
3	30	95	30-Mar-95	-0.0767	0.0603	-0.0133	-0.0036	-0.0384	0.0302	-0.0343	-0.0005	-0.0067	-0.0018	-0.0025	-0.0008	-0.0286	-0.0458
3	25	96	25-Mar-96	-0.0779	0.0606	-0.0146	-0.0041	-0.0390	0.0303	-0.0347	-0.0009	-0.0073	-0.0021	-0.0026	-0.0009	-0.0516	-0.0516

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 16
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0240	0.0088	0.0057	-0.0211	-0.0120	0.0044	-0.0082	0.0000	0.0029	-0.0106	0.0068	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0240	0.0086	0.0056	-0.0211	-0.0120	0.0043	-0.0082	0.0000	0.0028	-0.0106	0.0067	-0.0001	0.0000	-0.0057
1	19	90	19-Jan-90	-0.0239	0.0087	0.0059	-0.0210	-0.0120	0.0044	-0.0082	0.0000	0.0030	-0.0105	0.0068	0.0000	0.0000	0.0000
3	2	90	02-Mar-90	-0.0239	0.0080	0.0056	-0.0214	-0.0120	0.0040	-0.0080	0.0002	0.0028	-0.0107	0.0068	0.0000	0.0115	0.0000
4	27	90	27-Apr-90	-0.0245	0.0050	0.0036	-0.0230	-0.0123	0.0025	-0.0074	0.0008	0.0018	-0.0115	0.0067	-0.0001	0.0458	-0.0057
5	14	90	14-May-90	-0.0239	0.0054	0.0043	-0.0226	-0.0120	0.0027	-0.0074	0.0008	0.0022	-0.0113	0.0068	0.0000	0.0458	0.0000
8	20	90	20-Aug-90	-0.0250	0.0062	0.0036	-0.0224	-0.0125	0.0031	-0.0078	0.0004	0.0018	-0.0112	0.0065	-0.0003	0.0229	-0.0172
10	29	90	29-Oct-90	-0.0237	0.0088	0.0059	-0.0207	-0.0119	0.0044	-0.0082	0.0000	0.0030	-0.0104	0.0067	-0.0001	0.0000	-0.0057
4	26	91	26-Apr-91	-0.0250	0.0061	0.0041	-0.0232	-0.0125	0.0031	-0.0078	0.0004	0.0021	-0.0116	0.0069	0.0001	0.0229	0.0057
8	7	91	07-Aug-91	-0.0264	0.0068	0.0041	-0.0237	-0.0132	0.0034	-0.0083	-0.0001	0.0021	-0.0119	0.0070	0.0002	-0.0057	0.0115
4	20	92	20-Apr-92	-0.0231	0.0064	0.0060	-0.0226	-0.0116	0.0032	-0.0074	0.0008	0.0030	-0.0113	0.0072	0.0004	0.0458	0.0229
3	28	94	28-Mar-94	-0.023	0.0062	0.006	-0.0227	-0.0115	0.0031	-0.0073	0.0009	0.0030	-0.0114	0.0072	0.0004	0.0516	0.0229
11	10	94	10-Nov-94	-0.0232	0.0070	0.0067	-0.0226	-0.0116	0.0035	-0.0076	0.0006	0.0034	-0.0113	0.0074	0.0006	0.0344	0.0344
3	30	95	30-Mar-95	-0.0237	0.0053	0.0059	-0.0235	-0.0119	0.0027	-0.0073	0.0009	0.0030	-0.0118	0.0074	0.0006	0.0516	0.0344
3	25	96	25-Mar-96	-0.0233	0.0060	0.0057	-0.0233	-0.0117	0.0030	-0.0074	0.0008	0.0029	-0.0117	0.0073	0.0005	0.0458	0.0286

Terra Tilt Field Data Sheet
Project: Hopkinton Dam - Outlet Channel East Wall
Plate No: 17
Initial Date: Nov. 30, 1989

Mo.	Dy.	Yr.	Date	Ao rdg	A180 rdg	Bo rdg	B180 rdg	Ao	A180	A avg	A cum.	Bo	B180	B avg.	B cum.	A Rot'n	B Rot'n
			Initial	-0.0456	0.0307	0.0816	-0.0970	-0.0228	0.0154	-0.0191	0.0000	0.0408	-0.0485	0.0447	0.0000	0.0000	0.0000
1	3	90	03-Jan-90	-0.0450	0.0304	0.0816	-0.0970	-0.0225	0.0152	-0.0189	0.0002	0.0408	-0.0485	0.0447	0.0000	0.0115	0.0000
1	19	90	19-Jan-90	-0.0452	0.0305	0.0818	-0.0970	-0.0226	0.0153	-0.0190	0.0001	0.0409	-0.0485	0.0447	0.0000	0.0057	0.0000
3	2	90	02-Mar-90	-0.0453	0.0299	0.0816	-0.0974	-0.0227	0.0150	-0.0189	0.0002	0.0408	-0.0487	0.0448	0.0001	0.0115	0.0057
4	27	90	27-Apr-90	-0.0470	0.0278	0.0805	-0.1000	-0.0235	0.0139	-0.0187	0.0004	0.0403	-0.0500	0.0452	0.0005	0.0229	0.0286
5	14	90	14-May-90	-0.0471	0.0290	0.0808	-0.0993	-0.0236	0.0145	-0.0191	0.0000	0.0404	-0.0497	0.0451	0.0004	0.0000	0.0229
8	20	90	20-Aug-90	-0.0481	0.0296	0.0813	-0.1000	-0.0241	0.0148	-0.0195	-0.0004	0.0407	-0.0500	0.0454	0.0007	-0.0229	0.0401
10	29	90	29-Oct-90	-0.0460	0.0316	0.0827	-0.0975	-0.0230	0.0158	-0.0194	-0.0003	0.0414	-0.0488	0.0451	0.0004	-0.0172	0.0229
4	26	91	26-Apr-91	-0.0472	0.0295	0.0813	-0.0997	-0.0236	0.0148	-0.0192	-0.0001	0.0407	-0.0499	0.0453	0.0006	-0.0057	0.0344
8	7	91	07-Aug-91	-0.0475	0.0283	0.0807	-0.1002	-0.0238	0.0142	-0.0190	0.0001	0.0404	-0.0501	0.0453	0.0006	0.0057	0.0344
4	20	92	20-Apr-92	-0.0453	0.0289	0.0818	-0.0985	-0.0227	0.0145	-0.0186	0.0005	0.0409	-0.0493	0.0451	0.0004	0.0286	0.0229
3	28	94	28-Mar-94	-0.0449	0.0286	0.0817	-0.0982	-0.0225	0.0143	-0.0184	0.0007	0.0409	-0.0491	0.0450	0.0003	0.0401	0.0172
11	10	94	10-Nov-94	-0.0454	0.029	0.0814	-0.0981	-0.0227	0.0145	-0.0186	0.0005	0.0407	-0.0491	0.0449	0.0002	0.0286	0.0115
3	30	95	30-Mar-95	-0.0451	0.0278	0.0810	-0.0985	-0.0226	0.0139	-0.0183	0.0008	0.0405	-0.0493	0.0449	0.0002	0.0458	0.0115
3	25	96	25-Mar-96	-0.0457	0.0282	0.0810	-0.0988	-0.0229	0.0141	-0.0185	0.0006	0.0405	-0.0494	0.0450	0.0003	0.0344	0.0172

SURVEY DATA

Project: Hopkinton Dam - Outlet Channel East Wall
Survey Data

Date Printed: Mar-97

Mo.	Dy.	Yr.	Date	Plate No. 1 delta x	elev.	elev. chg	Plate No. 2 delta x	elev.	elev. chg	Plate No. 3 delta x	elev.	elev. chg	Plate No. 4 delta x	elev.	elev. chg	Plate No. 5 delta x	elev.	elev. chg
5	15	73	15-May-73	0.000	385.351	0.000	0.000	385.360	0.000	0.000	385.265	0.000	0.000	385.263	0.000	0.000	385.212	0.000
1	29	74	29-Jan-74	0.020	385.359	0.008	0.030	385.366	0.006	0.020	385.270	0.005	0.020	385.270	0.007	0.010	385.219	0.007
6	25	75	25-Jun-75															
4	28	76	28-Apr-76	0.020	385.365	0.014	0.010	385.376	0.016	0.020	385.276	0.011	0.010	385.274	0.011	0.010	385.226	0.014
11	3	77	03-Nov-77	0.000	385.349	-0.002	0.000	385.356	-0.004	0.000	385.271	0.006	0.000	385.256	-0.007	0.000	385.208	-0.004
5	23	78	23-May-78	0.020	385.354	0.003	0.030	385.364	0.004	0.050	385.266	0.001	0.050	385.266	0.003	0.020	385.216	0.004
11	15	87	15-Nov-87	0.049	385.360	0.009	0.010	385.370	0.010	0.080	385.270	0.005	0.099	385.270	0.007	0.070	385.220	0.008
4	26	89	26-Apr-89	0.085	385.350	-0.001	0.115	385.370	0.010	0.115	385.270	0.005	0.115	385.270	0.007	0.095	385.220	0.008
12	8	89	08-Dec-89	0.088	385.353	0.002	0.125	385.361	0.001	0.125	385.269	0.004	0.140	385.268	0.005	0.117	385.218	0.006
1	17	90	17-Jan-90	0.145	385.350	-0.001	0.212	385.366	0.006	0.224	385.269	0.004	0.216	385.268	0.005	0.203	385.219	0.007
5	3	90	03-May-90	0.105	385.357	0.006	0.130	385.366	0.006	0.135	385.268	0.003	0.125	385.266	0.003	0.123	385.217	0.005
4	23	91	23-Apr-91	0.078	385.365	0.014	0.112	385.375	0.015	0.112	385.280	0.015	0.108	385.275	0.012	0.102	385.230	0.018
5	23	94	23-May-94	0.130	385.419	0.068	0.160	385.430	0.070	0.170	385.331	0.066	0.160	385.330	0.067	0.160	385.279	0.067
11	9	94	09-Nov-94	0.160	385.392	0.041	0.205	385.401	0.041	0.170	385.306	0.041	0.185	385.305	0.042	0.160	385.253	0.041
3	15	96	15-Mar-96	0.130	385.371	0.020	0.220	385.384	0.024	0.210	385.291	0.026	0.220	385.289	0.026	0.190	385.242	0.030

Mo.	Dy.	Yr.	Date	Plate No. 6 delta x	elev.	elev. chg	Plate No. 7 delta x	elev.	elev. chg	Plate No. 8 delta x	elev.	elev. chg	Plate No. 9 delta x	elev.	elev. chg	Plate No. 10 delta x	elev.	elev. chg
5	15	73	15-May-73	0.000	385.221	0.000	0.000	385.103	0.000	0.000	385.091	0.000	0.000	385.090	0.000	0.000	385.113	0.000
1	29	74	29-Jan-74	0.000	385.222	0.001	0.000	385.109	0.006	0.000	385.094	0.003	0.010	385.092	0.002	0.010	385.118	0.005
6	25	75	25-Jun-75	0.010	385.214	-0.007	0.015	385.101	-0.002	0.010	385.088	-0.003	0.015	385.083	-0.007	0.022	385.110	-0.003
4	28	76	28-Apr-76	0.000	385.226	0.005	0.000	385.115	0.012	0.010	385.100	0.009	0.020	385.098	0.008	0.030	385.123	0.010
11	3	77	03-Nov-77	-0.010	385.208	-0.013	-0.010	385.099	-0.004	-0.010	385.086	-0.005	0.010	385.082	-0.008	0.020	385.115	0.002
5	23	78	23-May-78	0.040	385.220	-0.001	0.050	385.109	0.006	0.020	385.094	0.003	0.040	385.096	0.006	0.055	385.120	0.007
11	15	87	15-Nov-87	0.080	385.220	-0.001	0.089	385.110	0.007	0.080	385.100	0.009	0.100	385.100	0.010	0.110	385.120	0.007
4	26	89	26-Apr-89	0.075	385.220	-0.001	0.100	385.110	0.007	0.090	385.100	0.009	0.120	385.100	0.010	0.130	385.120	0.007
12	8	89	08-Dec-89	0.128	385.220	-0.001	0.118	385.110	0.007	0.118	385.098	0.007	0.130	385.096	0.006	0.140	385.121	0.008
1	17	90	17-Jan-90	0.210	385.226	0.005	0.197	385.114	0.011	0.183	385.098	0.007	0.201	385.099	0.009	0.221	385.128	0.015
5	3	90	03-May-90	0.119	385.221	0.000	0.121	385.109	0.006	0.119	385.095	0.004	0.136	385.098	0.008	0.145	385.119	0.006
4	23	91	23-Apr-91	0.110	385.235	0.014	0.105	385.125	0.022	0.095	385.110	0.019	0.115	385.110	0.020	0.112	385.135	0.022
5	23	94	23-May-94	0.170	385.251	0.030	0.170	385.173	0.070	0.160	385.158	0.067	0.180	385.157	0.067	0.200	385.181	0.068
11	9	94	09-Nov-94	0.170	385.261	0.040	0.180	385.146	0.043	0.160	385.131	0.040	0.190	385.126	0.036	0.205	385.153	0.040
3	15	96	15-Mar-96	0.190	385.244	0.023	0.190	385.135	0.032	0.180	385.120	0.029	0.200	385.121	0.031	0.210	385.148	0.035

Mo.	Dy.	Yr.	Date	Plate No. 11 delta x	elev.	elev. chg	Plate No. 12 delta x	elev.	elev. chg	Plate No. 13 delta x	elev.	elev. chg	Plate No. 14 delta x	elev.	elev. chg
5	15	73	15-May-73	0.000	385.120	0.000	0.000	385.085	0.000	0.000	385.083	0.000	0.000	385.070	0.000
1	29	74	29-Jan-74	0.020	385.121	0.001	0.000	385.088	0.003	0.000	385.083	0.000	0.010	385.067	-0.003
6	25	75	25-Jun-75	0.028	385.114	-0.006	0.011	385.083	-0.002	0.011	385.081	-0.002	0.027	385.063	-0.007
4	28	76	28-Apr-76	0.050	385.121	0.001	0.020	385.091	0.006	0.015	385.089	0.006	0.035	385.074	0.004
11	3	77	03-Nov-77	0.030	385.113	-0.007	-0.010	385.079	-0.006	-0.030	385.079	-0.004	0.000	385.060	-0.010
5	23	78	23-May-78	0.075	385.123	0.003	0.020	385.076	-0.009	0.010	385.084	0.001	0.025	385.069	-0.001
11	15	87	15-Nov-87	0.100	385.130	0.010	0.020	385.090	0.005	0.000	385.090	0.007	0.020	385.070	0.000
4	26	89	26-Apr-89	0.120	385.130	0.010	0.010	385.090	0.005	0.010	385.090	0.007	0.020	385.070	0.000
12	8	89	08-Dec-89	0.138	385.129	0.009	0.025	385.089	0.004	0.028	385.085	0.002	0.035	385.070	0.000
1	17	90	17-Jan-90	0.187	385.129	0.009	0.063	385.089	0.004	0.015	385.087	0.004	0.021	385.068	-0.002
5	3	90	03-May-90	0.140	385.122	0.002	0.017	385.088	0.003	0.003	385.084	0.001	0.015	385.070	0.000
4	23	91	23-Apr-91	0.110	385.140	0.020	0.002	385.105	0.020	0.005	385.100	0.017	0.015	385.080	0.010
5	23	94	23-May-94	0.180	385.180	0.060	0.040	385.140	0.055	0.010	385.135	0.052	0.020	385.120	0.050
11	9	94	09-Nov-94	0.140	385.150	0.030	0.030	385.114	0.029	0.035	385.108	0.025	0.015	385.089	0.019
3	15	96	15-Mar-96	0.200	385.153	0.033	0.030	385.108	0.023	0.020	385.108	0.025	0.020	385.084	0.014

APPENDIX C -- CRREL REPORT

Deformation of a retaining wall by ground freezing

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ABSTRACT: Field measurements were made of the horizontal movement of a large retaining wall in Hopkinton, NH, USA. The reinforced concrete retaining wall is part of an earthen dike on the downstream side of an earth-filled dam. The dike is used to separate an existing wood-cribbed dam and its associated forebay pool from the outlet channel of the earth dam. The wall, completed in 1963, is 71 m long and varies in height from 5.7 to 10.7 m. Previous surveys have indicated that outward displacements at the top of the wall occur during the winter and rebound partially during the spring. Observations of the wall show severe, permanent deformation. The owner of the dam—the US Army Engineer Division, New England—is concerned about the stability of the wall and plans on doing remedial work shortly. Prior to the 1995–96 winter season, the US Army Cold Regions Research and Engineering Laboratory installed various sensors on and behind the wall to continuously measure these displacements and to provide information for the repair strategy. The measurements indicate that the movement is frost related. Horizontal movement at the top of the wall of 20 mm, and increased earth pressure behind the wall of almost 200 kPa, were measured during the period of frost penetration. As the frost subsided in the spring, the earth pressure approached pre-winter values. Although the displacement at the top of the wall did rebound, it did not recover completely. This paper will present and discuss data recorded during the 1995–96 winter. These will include temperatures on the face of the wall, as well as the soil behind it, pressure between the wall and backfill material, lateral displacement at the top of the wall, and the angle of rotation along the face of the wall.

1 BACKGROUND

1.1 *Site*

The retaining wall is part of the Hopkinton-Everett reservoir system and is located in the town of Hopkinton, NH, on the Contoocook River, approximately 15 km west of Concord, NH. Construction of the project was started in November 1959 and completed in July 1963. The dam is rolled earth-fill with rockfill slope protection and is approximately 240 m long by 22 m high. Figure 1a shows the outlet works being separated by a concrete retaining wall (71 m long) and a rock-filled crib-type timber dam (100 m long) with the stilling basin on the west side of the dike and the forebay pool on the east. The forebay pool is used to supply water to a nearby paper mill. Figure 1b shows the difference in elevation of the stilling basin and forebay pool of approximately 10 m.

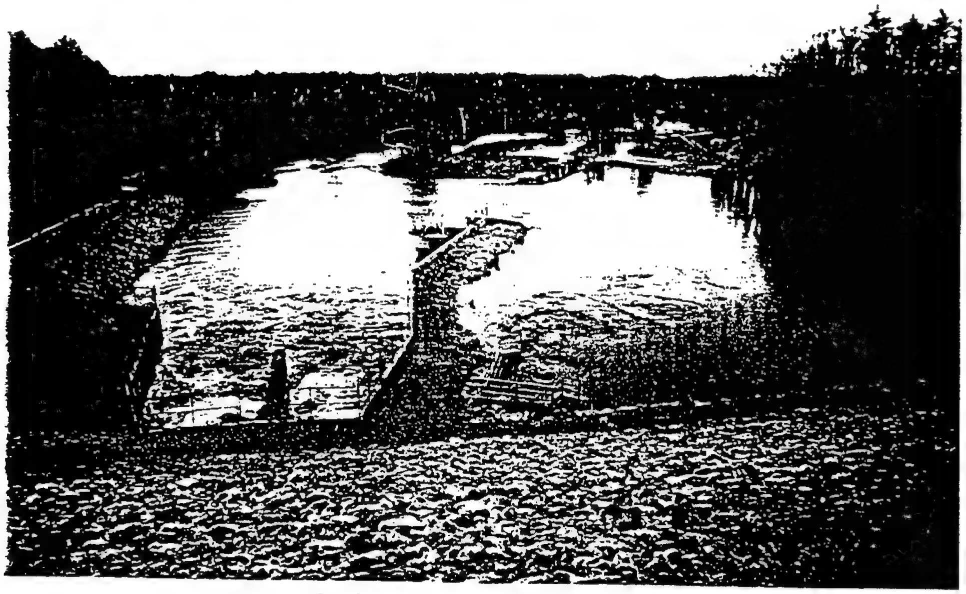
The site has an elevation of 118 m and a mean annual precipitation of 945 mm. The mean annual air temperature is 7.1°C. The mean annual air freezing index, and the 1-in-100-year index, are 14,800 h°C and 21,300 h°C, respectively.

1.2 *Retaining wall and fill material*

Figure 2 illustrates a section of the retaining wall. The wall is made of reinforced concrete and is 0.46 m thick at the top and increases to 1.98 m at its base. The wall sits on a keyed base that is 2 m thick. There are construction joints every 3.66 m vertically and expansion joints that separate the wall into monoliths every 6.1 m horizontally. The bulk of the soil behind the wall is specified on construction drawings to be a locally available "impervious fill." The soil placed within a meter of the wall is specified as a "special fill," indicating that it was compacted by hand-tamping only. Above these materials is a layer of gravel and a layer of rockfill. Inspection during this project revealed the surfaces depicted in Figure 2. While the forebay pool level is varied slightly throughout the year, the fill soil remains below the water table.

1.3 *Wall movement*

Between inspections in 1967 and 1972, it was found that the wall at the second monolith upstream of the wooden crib dam had displaced outward at its top 20



a. Outlet works, looking south.

b. Retaining wall, looking west.

Figure 1. Hopkinton Dam.

mm relative to the first monolith, which is prevented from large movements by its rigid connection to the abutment shown in Figure 1. Similar movements were noted in other monoliths. In 1972 a baseline survey was established using permanently mounted monuments. Since then, the top of the wall has displaced outward 60 mm (see Figure 3), averaging 2–3 mm each year. Surveys performed in winter and subsequent spring months revealed that the maximum annual displacement occurred during the winter, with a partial rebound during the spring. Observations and additional measurements indicated that these movements resulted from tilting or flexural deformation of the wall

The owner of the dam had concerns that the base of the wall may be sliding or tilting and had several exploratory borings drilled. It was found that the soil under the footings was a very dense glacial till and that there was no indication of footing movement. It was concluded that the tilting was taking place within the wall itself. However, it was not known if the movement was frost related.

1.4 *Instrumentation*

During the fall of 1994, the second monolith was instrumented to examine the seasonal variation and pro-

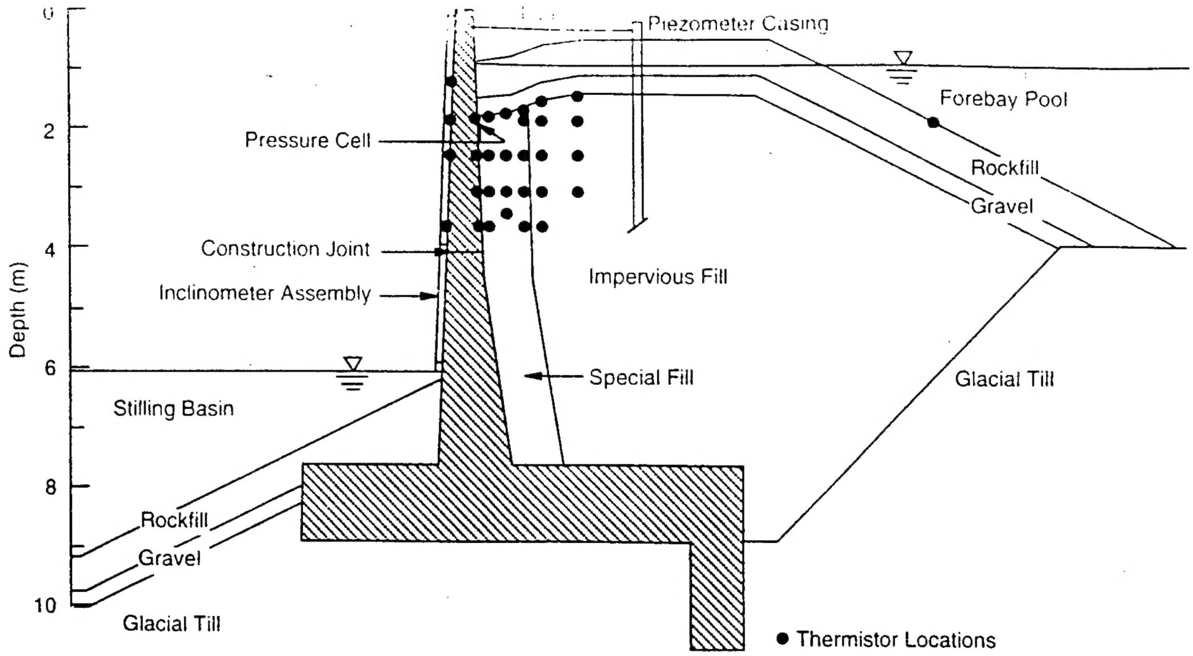


Figure 2. Typical section of retaining wall and instrumentation locations.

Figure 3. Horizontal displacement between the first and second monoliths.

files of its displacements. Of interest also were the temperatures of the air, wall, soil, and water, and the magnitude of the pressure causing the movement.

Figure 2, which depicts the second monolith section, illustrates the locations of the sensors: 30 thermistor-type temperature sensors were installed, 26 of these being placed in the upper 2.5 m of impervious fill immediately behind the wall (a silty clay with a dry density of 2066 kg/m^3), and 4 being placed on the face of the wall. An additional thermistor was installed during October 1995 in the forebay pool at a depth of 1–2 m. Air temperature is recorded approximately 0.5 km from the wall, independently from this instrumentation.

Two linear motion potentiometers (LMP) were installed to monitor the horizontal movement at the top of the wall. Each LMP was anchored to the wall at one end and to a piezometer casing at the other. Since the LMPs measure the relative movement between their anchor points, movements of the piezometer casings—the reference points—are of concern. To provide a comparison of wall section movements, one LMP (LMP-North) was attached to the second monolith from the abutment and the other (LMP-South) was attached to the fourth monolith.

To establish profiles of the wall displacements, a vibrating-wire inclinometer assembly was installed on the face of the second monolith. The assembly contains three 1.95-m inclinometer sections, each with a sensor to independently measure rotation at its top relative to its bottom. The assembly is housed within a tube (seen as a vertical line in Figure 1b) that is connected to the wall at the ends of the sections. The des-

ignations "top," "middle," or "bottom" inclinometer identify their relative positions.

One vibrating-wire earth pressure cell was installed between the wall and the fill of the second monolith. It was placed approximately 0.5 m below the surface of the impervious fill. Care was taken during installation that there was firm contact between the soil and wall.

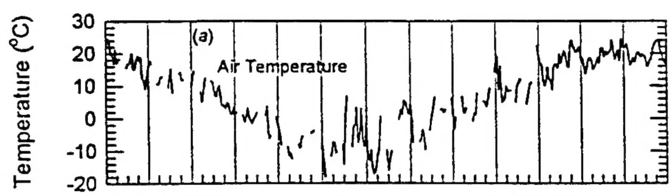
All sensors are connected to a solar-powered data recorder that is set to provide readings every 2 hours. Technical difficulties with this system delayed its start-up until March of 1995, while further difficulties have caused only minor interruptions.

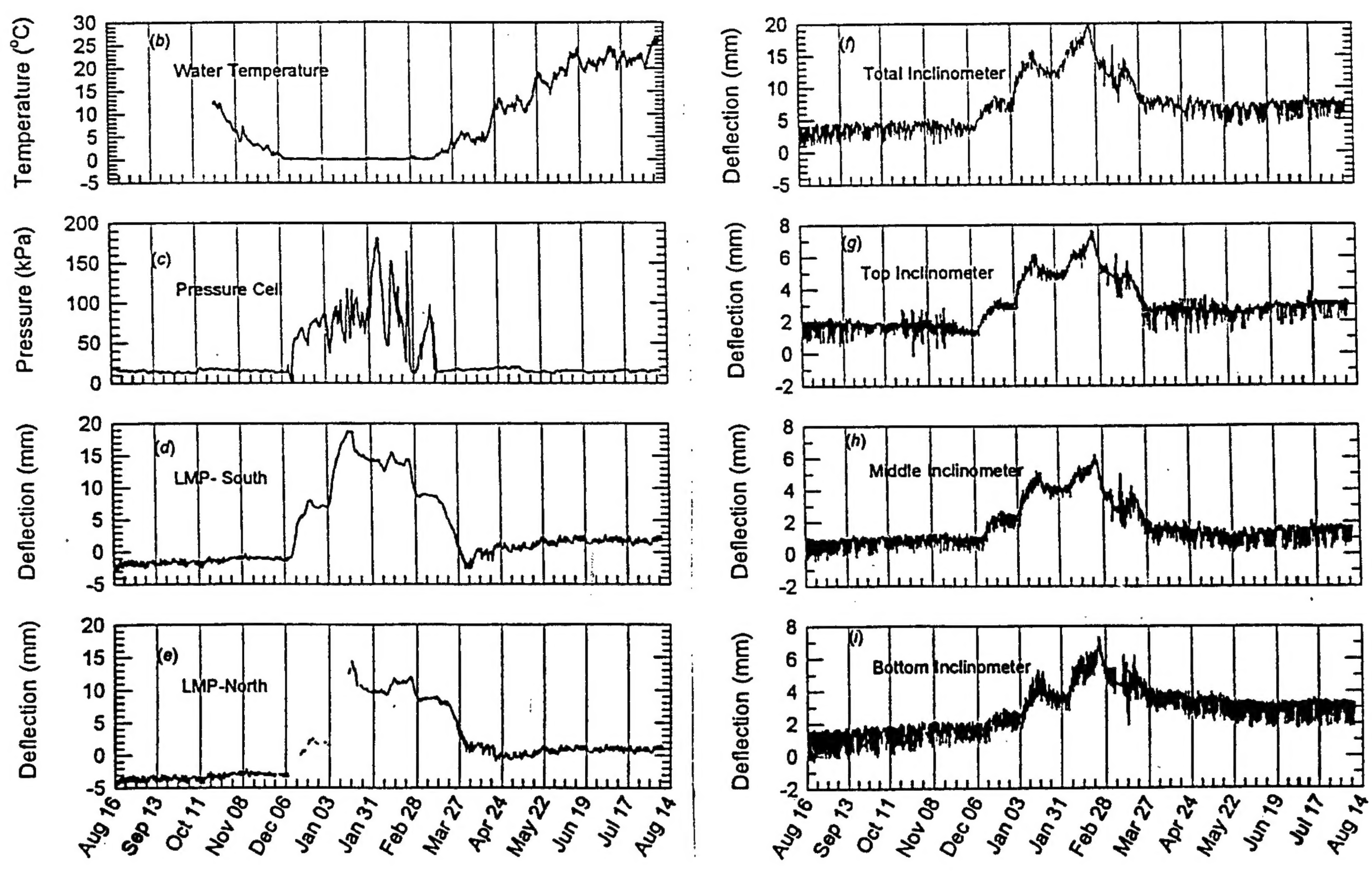
2 INSTRUMENT MEASUREMENTS FOR THE 1995–96 WINTER SEASON

Measurements illustrating climatic data and wall and soil response histories from the 1995–96 winter season are presented in Figures 4 through 6. Figure 4 contains nine graphs (parts a–i) showing temperature, pressure, and deflection data for the period August 1995 to August 1996. The air and forebay pool water temperatures are presented in Figures 4a and b, respectively, while data from the pressure cell is depicted in Figure 4c. Deflections at the top of the wall relative to the piezometer casings are shown in the LMP readings in Figures 4d and e. Deflections calculated from the inclinometer rotational measurements are shown in the remaining parts. Figures 4g–i contain deflections from the top, middle, and bottom inclinometers, respectively, while Figure 4f totals the three inclinometer deflections, providing a displacement measure for the top of the wall relative to the base of the bottom inclinometer. Zero values in the pressure cell, LMP, and inclinometer graphs correspond to the initial readings at the time of installation during the Fall of 1994; positive deflections in the LMP and inclinometer graphs correspond to outward movements of the wall.

Contours of temperature calculated from the in-soil thermistor measurements are shown in Figure 5, which has 11 graphs presenting soil temperatures at 2-week intervals from 6 December through 24 April. The contours are superimposed on a cross section showing the upper 4 m of the wall and the adjacent fill within 2–2.5 m of the wall.

A sequence of wall profiles is shown in the shaded region in Figure 6. The profiles were calculated from the inclinometer readings at weekly intervals from 6 December through 24 April. Figure 6 gives 21 pro-





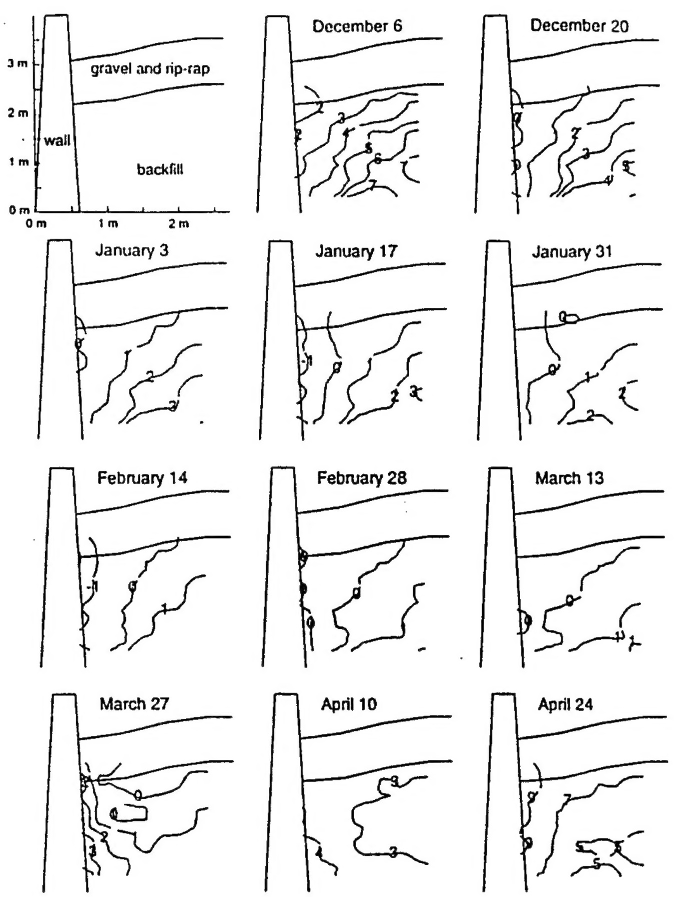


Figure 5. Temperature contours behind the second monolith.

files, either whole or in-part, depending upon their position in the sequence. Each profile comprises three line segments representing the sections of the inclinometer assembly—the bottom, middle, and top. The deflections indicated are those relative to the wall position on 6 December and to the base of the bottom inclinometer.

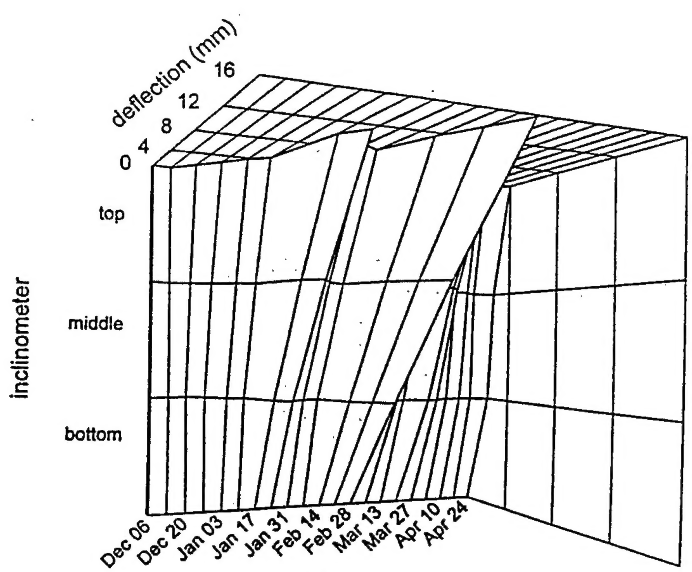


Figure 6. Retaining wall profile.

3 DISCUSSION

The winter of 1995–96 was warmer than usual at the site, having a freezing index of approximately 14,000 h°C, which is slightly below the mean. The air temperatures and forebay pool water temperatures indicated in Figures 4a and b further characterize the season, but also provide "driving" temperatures for heat transfer through the wall and the saturated fill behind the wall. Of particular interest are the number of thawing events revealed by the wintertime air temperature data and the lack of variation in the water temperature from the beginning of December to the end of March. The influx of new water into the forebay pool and its latent heat capacity appear to have kept the temperature at the sensor location just slightly above freezing. Visual observations further indicated that the forebay pool never froze during the winter.

The temperature contours in Figure 5 highlight the upper 2.5 m of the impervious fill in which the thermistors were placed behind the wall. A greater susceptibility to heat loss is evident in this corner area as the soil against the wall and immediately below the gravel is the first to freeze, reflecting losses through the narrow upper portion of the wall and upward through the gravel and rockfill layer. This is also the area that, later in the season, had the greatest frost penetration horizontally away from the wall, and the area in which the pressure cell was installed.

The pressure cell measurements shown in Figure 4c are relatively constant until early December when frost first penetrates into the soil behind the wall. The pressure generally increases with the progression of the freezing front to a maximum pressure of 170 kPa in early February relative to the early December value. Most of the peaks and valleys of the graph correspond to changes in the air temperature and associated freezing or thawing of the backfill. The highest peak occurs during an especially cold period in February, while the prominent valleys follow or coincide with midwinter thawing events. The complexity of the soil–wall interaction is hinted at by the lack of similar peaks and valleys in the deflection histories (Figure 4d–e), which reveal that wall movements are less frequent and less dramatic than the variations of pressure at the location of the pressure cell. It is interesting to note that the pressure returns to pre-freezing values before the frost is totally out of the soil, but only after the thaw does the wall rebound.

The individual inclinometer graphs in Figure 4g–i show deflection histories with similar magnitudes and variations. Each reveals a seasonally induced permanent deflection by a comparison of the reading after thaw to the early December value. The top and bot-

tom inclinometer data indicate the largest permanent deflection—1 to 2 mm—while the middle inclinometer shows less than 1 mm deflection. In the total inclinometer graph of Figure 4f, a permanent total deflection of nearly 4 mm is indicated.

Deflections at the top of the wall from the LMPs (Figure 4d and e) indicate a maximum measured deflection of 20 mm for LMP-South relative to its early December value. This occurred in mid-January, when the total relative deflection of the inclinometers was 5–10 mm less in magnitude. The inclinometer maximum deflection occurred during late February, but was at this time nearly equal to the LMP-South deflection, again considering relative values. A reason for this difference is not apparent, although movement of the piezometer casing (the LMP-South anchor), or the complexity of the soil–wall interaction, may be causes. Permanent seasonal deflections indicated by the LMPs are similar to the magnitude shown by the inclinometer total—nearly 4 mm. However, fluctuations in the post-thaw readings obscure a distinct measure of this.

The wall profile sequence in Figure 6 illustrates the outward and retracting movements of the wall during the freezing season. While bending is evident in the profiles, the figure shows the week-by-week deformations to be predominantly rotational, especially following positive movements. This indicates that the wall deformations are associated more with tilting—at least relative to the base of the bottom inclinometer—than with flexure. The permanent deformation reflected in the final profile shows a "bulge" at the base of the middle inclinometer. This is likely due to deformations around a construction joint located midway between the top and bottom of this inclinometer section. Indeed, visual inspections show a slight outward permanent deflection at the location of this joint.

4 CONCLUSION

Measurements taken during the 1995–96 winter indicate that the wall deflection is caused by ground freezing. While there have been no investigations to determine the existence of ice lenses during the winter season, the loading causing the deflection is apparently due to frost heaving pressures within the saturated silty clay behind the wall. When the soil freezes, there is an almost immediate increase in the pressure and deflection out of the wall. Wall deflections appear to be at their greatest when the frost is at its deepest point. As the soil thaws, the pressure decreases to pre-season values and the wall rebounds except for a permanent deflection of 3–4 mm. This agrees reasonably well with historical averages of 2–3 mm per year.

The indications that the deformation of the wall is more tilting than bending is of great interest to the owners of the wall, as they work to identify the structural behavior of the wall prior to initiating remedial work. The owners characterize the ratchetting deformations of the wall as serious, and are using the measurements described here to plan their remedial work appropriately.